AN ORAL REHYDRATION SOLUTION WITH FLAXSEED GUM

A Thesis Submitted to the
College of Graduate and Postdoctoral Studies
In Partial Fulfillment of the Requirements
For the Degree of Master of Science
In the College of Pharmacy and Nutrition
University of Saskatchewan
Saskatoon

By

Shuyu Shang

PERMISSION TO USE

In presenting this thesis/dissertation in partial fulfillment of the requirements for a Postgraduate degree from the University of Saskatchewan, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for copying of this thesis/dissertation in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis/dissertation work or, in their absence, by the Head of the Department or the Dean of the College in which my thesis work was done. It is understood that any copying or publication or use of this thesis/dissertation or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of Saskatchewan in any scholarly use which may be made of any material in my thesis/dissertation.

Requests for permission to copy or to make other uses of materials in this thesis in whole or part should be addressed to:

Dean of the College of Pharmacy and Nutrition
104 Clinic Place
University of Saskatchewan
Saskatoon, Saskatchewan S7N 2Z4 Canada
Canada

Dean
College of Graduate and Postdoctoral Studies
University of Sakatchewan
116 Thorvaldson Building, 110 Science Place
Saskatoon, Saskatchewan S7N 5C9
Canada

ABSTRACT

Flaxseed is an excellent source of both soluble and insoluble dietary fiber. The presence of mucilage stored in the seed's outer layers gives flaxseed unique characteristics compared to most other oilseeds. Based on currents studies, flaxseed gum (FG) contributes many health benefits and potential functional properties. For example, it provides water-holding capacity, mitigates obesity, and inhibits Hepatitis B virus.

This study investigated FG utility as a commercial oral rehydration solution with acceptable physicochemical and sensory characteristics. The extraction yield of three flaxseed cultivars at 60 and 80°C were determined. The pH, colour, neutral sugar, and viscosity were analyzed on two FG concentration (0.50% and 1.00%) of three different flax cultivars (CDC Bethune, CDC Glas, and CDC Sorrel). The sensory study was conducted with 12 semi-trained participants to evaluate FG beverage for the attributes of colour desirability, odour/smell, texture/mouth feel, taste/flavour intensity, after-taste intensity, and overall product acceptability.

The yield of solids was greatest for CDC Glas extracted at 80°C followed by CDC Bethune extracted at the same temperature. Flaxseed cultivar, FG concentration, and gum extraction temperature affected the physicochemical properties of the beverage product. All formulated solutions had circum-neutral pH, with the lowest pH measure in solutions made from 1.00% FG beverage extracted from CDC Glas. This is similar to conventional oral rehydration solution. FG beverage made with CDC Bethune (80°C) had lowest optical density value and, therefore, had the best appearance. FG beverage prepared with CDC Bethune (80°C) contained the highest neutral sugar content. All formulated solutions demonstrated shear thinning rheology properties similar to conventional oral rehydration solutions. Taken together, the physicochemical properties suggest that FG beverage made with 60°C CDC Bethune and 80°C CDC Glas may be the better choices for superior appearance, mouthfeel and health benefits.

The sensory study suggested that FG beverage made with FG extracted from CDC Glas at 80°C (1.00% w/v) was the most popular formulation. This formulation exhibited a desirable appearance and least taste and after-taste intensities amongst all the FG beverage formulations and had acceptable odour and texture attributes. The addition of orange flavour compound significantly lowered the flavour intensity of the FG beverage.

In conclusion, the FG beverage can exhibit desirable physicochemical and sensory evaluation results, as well as satisfactory product acceptability. Future studies will focus on product consistency, shelf stability, and antiviral oral rehydration solutions with added FG.

ACKNOWLEDGEMENTS

I would first like to express my sincere gratitude to my supervisors, Dr. Martin Reaney and Dr. Jane Alcorn for the continuous support of my Master study and related research. Their guidance helped me all the time with research and writing of this thesis. They also offered me lots of opportunities to attend academic conferences to present my work.

I would like to thank the rest of my thesis committee: Dr. Supratim Ghosh, Dr. Yongfeng Ai, and Dr.Ildiko Badea, for their insightful comments and encouragement.

I would also like to thank the panelists who were involved in the sensory study for this research project. Without their passionate participation and input, the survey could not have been successfully conducted.

I would also like to acknowledge my labmates for their support and for all the fun we have had in the last three years.

I would like to express my appreciation to the funding support from my supervisors, and the funding source, the Agriculture Development Fund of the Saskatchewan Ministry of Agriculture.

Finally, I am grateful to all my friends for all the joy they brought for me and their encouragement. Also, I must express my very profound gratitude to my parents, brother, and to my husband for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them.

Thank you all.

Shuyu Shang

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ANOVA	**Analysis of variance**
AOAC	**Association of Official Analytical Chemists**
AFG	**Acidic fraction gum**
ALA	**Alpha linolenic acid**
CDC	**Crop Development Center**
°C	**Degree Celsius**
FG	**Flaxseed gum**
HBV	**Hepatitis B virus**
h	**Hours**
LSD	**Least significant difference**
MW	**Molecular weight**
n.d.	**No date**
NFG	**Neutral fraction gum**
QDA	**Quantitative descriptive analysis**
Rhamnogalacturonan-I	**RG-I**
s	**Second**

SD	**Standard deviation**
SFG	**Soluble flaxseed gum**
SK	**Saskatchewan**
UV	**Ultraviolet**
Vis	**Visible**
v/v	**Volume/volume**
w/v	**Weight/volume**

1. INTRODUCTION

1.1. Overview

Flax (*Linum usitatissimum*), a traditional crop plant, is widely grown in North America, Europe, and Asia (Kajla, Sharma, and Sood 2015). It is the third largest oilseed crop in Canada after canola and soybean. In addition to production for industrial oil and fiber, flax is also cultivated for nutritional products. The main classes of bioactive components in flax include essential fatty acids (alpha linolenic acid; ALA), good quality protein, lignans, and soluble dietary fiber (Goyal et al. 2014; Berglund 2002). Together these compounds are important to the demand for flax and flaxseed products in functional foods (Kajla, Sharma, and Sood 2015).

Flaxseed is an excellent source of both soluble and insoluble dietary fiber. The presence of mucilage in the seed's outer layers gives flaxseed unique characteristics compared to most other oilseeds. Flaxseed gum (FG) consists of acidic and neutral polysaccharides. Based on current studies, FG contributes many health benefits and potential functional properties. For example, it provides water-holding capacity, mitigates obesity, and inhibits Hepatitis B Virus (Wang et al. 2017). However, FG isolates have not been widely utilized due to limited information regarding their structures, and knowledge of their immunomodulatory activity, anti-viral activity, and effects on organoleptic properties (Wang et al. 2017). Therefore, the current study investigated FG utility as a bioactive ingredient for beverages that had acceptable sensory characteristics that would help with consumer acceptance. The appearance, aroma, texture, and taste intensity of FG were also investigated to optimize both the sensory characteristics and acceptance of FG beverage. Also, the physicochemical properties of FG product were analyzed.

1.2. Hypothesis

Based on conventional products of oral rehydration solutions, FG beverage solution can be formulated to give satisfactory physicochemical properties and sensory characteristics.

1.3. Objectives

- To formulate an oral rehydration solution with flaxseed gum (FG) based on the conventional oral rehydration products on the market.

- To investigate the physicochemical and sensory properties of a formulated FG beverage.

- To optimize the formulation according to the physicochemical properties and sensory characteristics and the addition of a flavour compound.

2. LITERATURE REVIEW

The global challenges of rising obesity, diabetes, and other health concerns have continually increased consumers' interests in healthy foods. Functional beverage, positioned between nutraceuticals and foods, is a tool for delivering high quality food elements to the consumer with additional health, nutritional, and well-being benefits (Haase 2010; Paquin 2009;). Oral rehydration solution has an established market sector as functional drinks through sales of oral rehydration solution fortified with electrolytes.

Polysaccharide gums have widespread use in food applications due to their ability to form gels in water or to induce viscosity in aqueous solution or to stabilize emulsions (Mirhosseini and Amid 2012; Glicksman 1963). Among all the polysaccharides gum, FG solution exhibits different chemical structure, which may offer FG a broad range of application in functional beverage, specifically with oral rehydration solution.

2.1. Flaxseed

Flax (*Linum usitatissimum*) was originally from Mesopotamia, and has been planted for over 5000 years, although it was principally used for textile fibres as cloths and paper (Carraro et al. 2012), while animal feed was the main utilization for flaxseed oil and its sub-products. Human consumption has steadily increased in the last two decades throughout the world (Cardello, Schutz, and Lesher 2007). Today, flax is cultivated in more than 50 countries with production of about 2,930,000 tonnes (FAO Production Year Book 2016). Flaxseed is widely grown in North America, Europe, and Asia (Kajla, Sharma, and Sood 2015). Canada is the world's largest producer with total production of 94,000 tonnes in 2015-2016 (Zienkiewicz 2017), which accounts for 33% of the global total. Canada is also the largest exporter of flaxseed (Oomah 2001). About 80% of globally traded flaxseed is produced in Canada with annual exports valued at CAN$ 150 - 180 million (Saskatchewan Flax Development Commission 2018). It is the third largest oilseed crop in Canada after canola and soybean. Most Canadian flaxseed is grown in the three prairie provinces of western Canada, especially in southern Manitoba, Saskatchewan, and Alberta (Canadian Food Inspection Agency 2018). The flaxseed grown in Western Canada is planted for the export market as flax oil, flaxseed meal, and flax fiber ("Saskatchewan Flax Development Commission - Varieties" n.d.). Saskatchewan has been the largest producing province in Canada since 1993 - 1994 (Saskatchewan Flax Development Commission 2018). In 2017, Saskatchewan seeded 364,200 hectares of flax, producing 447,600 tonnes of flaxseed, which accounted for 82% of flaxseed production in Canada. Now, Saskatchewan is a quality and quantity world-leading producer of oilseed flax. About 25% of the global flaxseed supply is produced in Saskatchewan alone ("Flax FAQs - CDC Flax - College of Agriculture and Bioresources - University of Saskatchewan" n.d.). As most of Saskatchewan's flaxseed is exported, the value has become an important enhancement to the Province's economy ("CDC Flax Breeding Program - CDC Flax - College of Agriculture and Bioresources - University of Saskatchewan" n.d.).

Flaxseed is flat and oval with a pointed tip and smooth glossy surface. The flaxseed composed of an embryo (or germ), a thin layer of endosperm, and two cotyledons encased in a seed coat (or hull) (Daun et al. 2003) (Fig. 2.1). The size of commercially cultivated flaxseed is slightly larger than sesame seed, though dimensions vary among cultivars. The typical length is 3.0 - 6.4 mm, width 1.8 - 3.4 mm, and thickness 0.5 - 1.6 mm (Coşkuner and Karababa 2007). Flaxseed colour ranges from golden yellow to reddish-brown and is determined by the amount of seed coat pigment. The seed weight is about 5 ± 1g/10000 (Daun et al. 2003). Flaxseed has a crisp and chewy texture and a pleasant, nutty taste (Morris 2007).

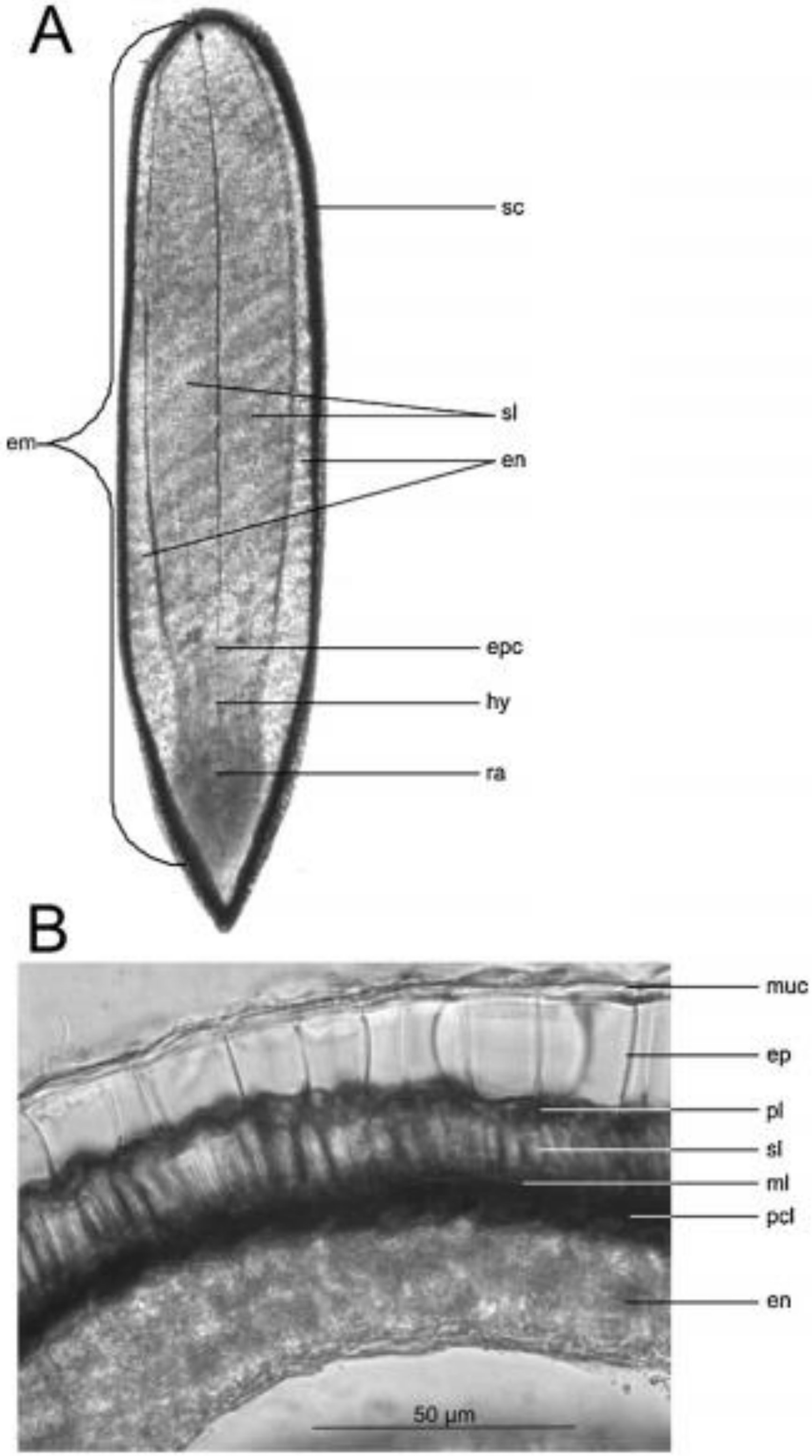


Figure 2.1 Flaxseed morphology. (A) Longitudinal section; (B) Cross-section of linseed; Abbreviations: (A) em, embryo; sc, seed coat; sl, seed leaves/cotyledons; en, endosperm; epc,

epicotyl; hy, hypocotyl; ra, radicle; (B) muc, mucilage cell; ep, epidermis; pl, parenchymatous; sl, sclerite layer; ml, membraniform layer; bl, brown layer; en, endosperm. Figures taken from (Zuk et al. 2015).

The total oil content in flaxseed is reported to be 30 - 40% (Kajla, Sharma, and Sood 2015). Up to 90% of which is poly-unsaturated fatty acid triglycerides (Ziolkovska 2012; Dorrell 1970). The high proportion of linolenic acid (>50%) in flaxseed oil provides drying properties, which is desirable for paint fabrication, varnishes, and linoleum flooring coverings (Flax council 2015). The oil is mainly stored in the endosperm of flaxseed while only relatively small amount of lipid is contained in the hull (Dorrell 1970). The traditional way to obtain flaxseed oil is though cold pressing or extraction from crushed seed, but the usage of dehulled flaxseed would offer advantages in flaxseed oil production (Zheng et al. 2003). The other way to increase the quality and yield of flaxseed oil is to remove the polysaccharides in the flaxseed before oil extraction, which will decrease the fiber content in the meal (Ziolkovska 2012).

The total protein in flaxseed constitutes 20 - 25% (Kajla, Sharma, and Sood 2015), with about 20% present as albumins (1.6S and 2S) and 80% as legumin-like proteins (11S and 12S) (Sammour 1999). Generally, the amino acid profile of flaxseed is comparable with soy, both of which are high in aspartic acid, glutamic acid, leucine, and arginine. The flaxseed proteins are structurally more lipophilic than soybean proteins (Oomah and Mazza 1993).

The total carbohydrate accounts for 20 - 28% (Kajla, Sharma, and Sood 2015), and can be classified into two groups, digestible carbohydrates and dietary fiber. Digestible carbohydrates can be digested by human enzymes and generally include simple sugars and starch. This part is only a very small percentage of flaxseed, and likely to be less than 1 - 2% (Vaisey-Genser and Morris 1997; Bhatty and Cherdkiatgumchai 1990). Most of the carbohydrate content exists as dietary fiber resistant to the action of human digestive enzymes. Flaxseed is unique from other whole grains because it is an excellent source of both soluble and insoluble dietary fiber (Mirhosseini and Amid 2012). The ratio of soluble to insoluble fibers ranges from 20:80 to 40:60 depending on the extraction method and chemical analysis used (Vaisey-Genser and Morris 1997; Hadley, Lacher, and Mitchell-Fetch 1992).

Minor components, for example, minerals, water soluble vitamins, phenolics, and lignans, are also found in flaxseed (Daun et al. 2003). Flaxseed properties are significantly affected by both genotype and environmental conditions during plant growth (Kaewmanee et al. 2014).

Among all the 300 cultivars of flax in the world, six Canadian varieties, CDC (Crop Development Center) Bethune, CDC Sorrel, CDC Arras, CDC Glas, Vimy, and Flanders, are prominent registered cultivars grown in Canada (Liu et al. 2016). All of these flaxseed cultivars were developed by the Crop Development Center, University of Saskatchewan (Saskatoon, SK, Canada), and designed primarily for production of industrial oil for export markets. Only more recently has flaxseed oil and seed been used in food supplements. Therefore, these cultivars represent the majority of internationally traded commercial flaxseed ("Saskatchewan Flax Development Commission - Varieties" n.d.). Among all six cultivars, CDC Bethune, CDC Sorrel, and CDC Glas, were selected for detailed investigations of their gum solutions on physicochemical and sensory properties in oral rehydration solution preparations, as these three cultivars are the most common species in the globally traded market, with comparably higher yield and higher percentage of FG.

CDC Bethune is considered to the one of the best characterized flax cultivars based on the numerous studies with a high consistent yield, medium time to maturity, medium maturity, medium oil content, and good lodging resistance ("CDC Flax Breeding Program - CDC Flax - College of Agriculture and Bioresources - University of Saskatchewan" n.d.; Rowland, Hormis, and Rashid 2002) CDC Sorrel is also bred and selected due to good performance on oil concentration, maturity and vigour of stand (Government of Canada n.d.). CDC Glas exhibits higher yields and stronger straw than CDC Bethune ("CDC Glas | SeCan" n.d.), with medium seed size and good lodging resistance (Booker, Rowland, and Rashid 2013).

2.2. Nutritional Profile of Flaxseed

Flaxseed oil has been widely used as a drying oil or painting oil in industry, while the demand for flaxseed has been largely increased due to consumer understanding of the relationship between health and diet. Flaxseed is considered to be a potential functional food ingredient, since it provides all kinds of health benefits as well as nutritional value (Eyres 2015). Canada is the first country in the world to allow a health-related claim on food labels for flaxseed, linking ground whole flaxseed to lower cholesterol (Zienkiewicz 2017). The existence of functional ingredients in flaxseed make it beneficial for critical disease like cardiovascular disease, cancer, diabetes, renal and bone disorder (Katare et al. 2012).

Flaxseed oil contains five main fatty acids: palmitic, stearic, oleic, linoleic, and ALA (Flax Council of Canada 2015). The high portion of ALA makes flaxseed a crucial source of α-linolenic acid for people on a vegetarian diet. In this case, it can also be an excellent fatty acid source to the population which do not have convenient access to seafood (El-Beltagi, Salama, and El-Hariri 2007). The protein in flaxseed is composed of 80% globulins and 20% glutelin (Hall III, Tulbek, and Xu 2006). It is considered as one of the most nutritious plant proteins (Morris 2007). The major lignan that exists in flaxseed is secoisolariciresinol diglycoside, which has a breast tumor-reducing impact (Chen et al. 2011) and protective effect against diabetes risk, as well as lower cholesterol (Adlercreutz 2007). The mucilage in flaxseed appears to play an important role in reducing coronary heart disease and diabetes, preventing colon and rectal cancer, and avoiding obesity (Franklin 2009). Together these compounds are important to the demand for flax and flaxseed products in functional foods (Kajla, Sharma, and Sood 2015).

2.3. Polysaccharide Gums

The history of using gums in industry and commerce could be traced back thousands of years all over the world. The term "gum" is used to describe a group of naturally occurring materials that have widespread industrial applications due to their ability to form gels in water or to induce viscosity in aqueous solution or to stabilize emulsions (Mirhosseini and Amid 2012; Glicksman 1963). The gums presenting with a large number of hydroxyl (-OH) groups significantly increase their affinity for binding water molecules. Structurally, gums utilized commercially are polysaccharides or the mixtures of polysaccharides, for examples of gum Arabic and FG. The application of a gum is selected depending on its functional properties, while each gum has its own individual characteristics and must be considered differently according to the particular application.

In the food industry, gums have been widely used primarily for their thickening, stabilizing, gelling, and textural properties in individual food products and to improve the overall quality and shelf life (Saha and Bhattacharya 2010; Waldt 1961). Gums have been commonly used as a food additive in various food formulations like soups, gravies, salad dressing, sauces, and toppings to achieve the desired viscosity and mouthfeel. Also, they are present in food products like ice creams, jams, jellies, cakes, and candies, to obtain the favored texture (Saha and Bhattacharya 2010). In recent years, these naturally plant derived polymers also have received attention due to their diverse pharmaceutical applications, such as diluents, binders, disintegrants in tablets, thickeners in oral liquids, protective colloids in suspensions, gelling agents in gels, and bases in suppositories (Prajapati et al. 2013). They are also applied variously in cosmetics, textiles, paints, and paper making (Jani et al. 2009).

Nowadays, researchers have mainly studied the polysaccharide gums due to their sustainable, biodegradable, and bio-safe characteristics (Rana et al. 2011). This increasing attention on research will greatly help the natural gums to stay in the market for their current applications and future applications.

2.4. Flaxseed Gum (FG)

Flaxseed contains both soluble and insoluble dietary fibers that are resistant to human digestive enzymes and constitutes up to 28% of seed dry weight. Flaxseed stands out from other oilseeds and cereals due to its high content of gums. The seed coat (hull) of flax consists of four layers. The outermost layer of flaxseed hull contains a thick mucilage layer, also known as the soluble fiber portion (Mazza and Biliaderis 1989), where flaxseed gums can be easily extracted from flaxseed, and constitutes about 8% of seed weight (Coşkuner and Karababa 2007). Thus, high content and easy extraction of flaxseed polysaccharides make flaxseed an excellent source of dietary fiber, also as a potential commercially viable source of gum. This mucilaginous material is a secondary cell wall polysaccharide, which is soluble in cold water (Biliaderis and Izydorczyk 2006).

Based on previous studies, FG contains 50 to 80% carbohydrate, 4 to 20% protein, and 3 to 9% ash (Fedeniuk and Biliaderis 1994). The variation is mostly caused by the raw material, for example the particular flaxseed cultivar, growing conditions, and the plant part used for extraction. Also the extraction solvent, pH, temperature, the form of raw materials and other extraction conditions would significantly impact the chemical and monosaccharide composition (Cui 2005; Wannerberger, Nylander, and Nyman 1991; Muralikrishna, Salimath, and Tharanathan 1987).

2.5. Flaxseed Gum Extraction

The mucilage is primarily obtained by aqueous extraction of the whole seed or meal. Based on the previous study, the yield, rheological properties, and compositional characteristics of FG vary with the pH, seed : water ratio, extraction temperature, and processing time (Koocheki et al. 2009).

2.5.1. Extraction of Mucilage from Flaxseed

FG's ability to easily dissolve in cold water allows the application of mild conditions to extract FG from raw materials. The traditional extraction method is to soak flaxseed in water and extract at different temperatures with continuous stirring from 3 to 16 hours (Cui 2000). The extraction conditions, for example, temperature, pH, and time all have significant impact on the yield, purity, chemical composition, and rheological properties of the flaxseed mucilage (Cui, Kenaschuk, and Mazza 1996; Fedeniuk and Biliaderis 1994; Mazza and Biliaderis 1989). A number of researchers have reported that with higher extraction temperatures, the gum yield would increase from 5 to 9%, but it would also increase the protein content in the mucilage (Cui et al. 1994). FG extracted at four temperature 30, 50, 70, and 90°C resulted in significant differences in monosaccharides and protein chemical composition. At 30 and 50°C, the extracted FG samples had higher levels of neutral monosaccharides and lower levels of acidic monosaccharides. Increasing extraction temperatures also increased the protein content (Kaushik et al. 2017). As described by Cui et al. (1994), the optimized extraction condition occurs at a temperature of 85 to 90°C for 2.5 to 3 h, a pH between 6.5 to 7.0, with the water : seed ratio of 13:1 to give high yields of FG (8%) with low levels of protein contaminants (< 8%).

The aqueous extract is then filtered or centrifuged to remove solid particles, followed by precipitation in organic ethanol solvent. The ethanol precipitation is applied not only for collection of the dissolved polysaccharides, but also for the removal of cyanogenic glycosides, which are the main antinutrients in flax and are likely to be extracted along with the mucilage (Daun et al. 2003). The final FG is obtained by freeze-drying or spray-drying (Biliaderis and Izydorczyk 2006). The freeze-drying normally results in FG with relative purity, free of antinutrients, and stable for storage materials (Jenkins 1995), while the products from spray-drying often have a lower viscosity due to the impact of high outlet temperature (Oomah and Mazza 2001).

Other than the extraction conditions of temperature, time and pH, the preparation of raw material will also be a significant aspect to determine FG characteristics. The preparation of raw material includes mechanical processing and swelling. The swelling consists of two stages: hydration and swelling (Ziolkovska 2012). In the mechanical processing, it is important for FG extraction to choose a proper form of raw material. Three common options are applied in the flaxseed preparation to extraction: whole seed, hull separation, and flaxseed meal. Whole seed demonstrates improved extraction of mucilage compared to the others, since it can reduce the protein amount in the mucilage (Fedeniuk and Biliaderis 1994; Bhatty 1993).

2.5.2. Extraction of Mucilage from Flaxseed Meal

Although flaxseed has been increasingly consumed as a human food, the industrial uses of flax oil still predominates the marketplace since the industrial revolution (Daun et al. 2003). As a result, a large amount of flaxseed meal is found in the industry as a by-product from flaxseed oil pressing. The seed crushing increases the possibility of extracting other substances, including proteins and tannin pigments, which would decrease the quality of mucilage (Ziolkovska 2012). The flaxseed mucilage extracted from flaxseed meal is suitable for using as an emulsifying agent and applied in chocolate milk and others food products, since it contains large amount of proteins (Biliaderis and Izydorczyk 2006).

2.5.3. Extraction of Mucilage from Flaxseed Hull

Since FG is mainly located in the outer layer of the seed coat, the extraction directly from flaxseed hull would be more efficient compared to the extraction of whole flaxseed or flaxseed meal, but the hull separation from flaxseed kernel is still a technical problem (Ziolkovska 2012), due to the extreme hardness of the hull and closed combination between flaxseed kernel and hull (Mridula 2013).

2.6. Flaxseed Gum Yield

The yield of FG obtained by extraction varies greatly depending on the extraction method and cultivar. There is little information regarding dietary fiber content among prominent flax cultivars. Liu et al. (2016) investigated FG from six Canadian flaxseed cultivars and determined FG yield (Table 2.1). There was significant variation in FG yield among cultivars with the cultivar Flanders

(14.45 ± 0.49 g/100 g seed) and CDC Glas (13.62 ± 0.33 g/100 g seed) having the highest yields. CDC Bethune afforded the lowest FG yield (9.33 ± 0.14 g/100 g seed). FG extraction yield can be a valid parameter for determining both functional properties and the economic viability of FG extraction. In other work done by Cui et al. (1996), FG yield from 6 cultivars varied from 5.5% to 7.9% (Table 2.2). Gum yield measurements for both studies were conducted according to a similar aqueous extraction procedure followed by precipitation with four volumes of ethanol (Chornick 2002). Reproducible yield results suggest that this method can be used to determine FG soluble fiber content. The qualitative and quantitative determination of gum yield from flaxseed has great importance in FG commercialization.

Table 2.1 Flaxseed gum (FG) yield, protein, neutral sugar, and acid sugar content of FG solutions for six Canadian cultivars (Data taken from Liu et al. 2016). Values are provided as mean ± SD.

Cultivar	**Yield (g/100 g seeds)**	**Protein (mg g^{-1} FG)**	**Sugar (mg g^{-1} FG)**	
			Neutral Sugar	**Acidic Sugar**
CDC Glas	**13.62 ± 0.33**	**64.9 ± 2.3**	**430 ± 39**	**98 ± 18**
Vimy	**12.75 ± 0.38**	**90.8 ± 4.7**	**389 ± 37**	**89 ± 25**
Flanders	**14.45 ± 0.49**	**73.2 ± 13.2**	**578 ± 22**	**111 ± 19**
CDC Sorrel	**12.71 ± 0.47**	**87.3 ± 3.5**	**367 ± 27**	**114 ± 23**
CDC Arras	**11.90 ± 0.35**	**88.3 ± 1.9**	**418 ± 28**	**117 ± 26**

CDC Bethune	**9.33 ± 0.14**	**56.6 ± 5.1**	**592 ± 84**	**181 ±17**

Table 2.2 Effect of cultivar on mucilage extract yields (percentage of seed weight) (Data taken from Cui et al. 1996).

Cultivar	Yield (%)
Norman	**7.9 ± 0.5**
Royal	**5.5 ± 0.2**
Reina	**6.7 ± 0.3**
22-87-2-159	**6.0 ± 0.2**
Verne	**6.0 ± 0.3**
Atlante	**6.0 ± 0.1**

2.7. Physicochemical Properties of Flaxseed Gum

FG has evoked tremendous interest in the food industry due to its physicochemical and functional properties and possible consideration as a food hydrocolloid. Soluble flaxseed gum (SFG) can be fractionated into a neutral fraction gum (NFG) (75%) and an acidic fraction gum

(AFG) (25%) using ion exchange chromatography (Qian et al. 2012; Warr et al. 2003; Cui, Kenaschuk, and Mazza 1996). Numerous studies of flaxseed mucilage properties have been carried out. Flaxseed mucilage can be used as a thickener, since its apparent viscosity aligns well to the Power Law model (Wu et al. 2010; Cui, Kenaschuk, and Mazza 1996), as a gelling agent (Chen, Xu, and Wang 2007), and foaming properties (Khalloufi et al. 2008, 2009; Mazza and Biliaderis 1989). These solution properties have led to studies of FG in salad dressing, carrot juice, and dairy desserts (Shakeel et al. 2013; Rabetafika et al. 2011; Stewart and Mazza 2000).

2.7.1. Chemical Composition of Flaxseed Gum

Two groups of polysaccharides polymers, a neutral arabinoxylan polysaccharide and an acidic rhamnogalacturonan-I (RG-I) polysaccharide, can be fractionated from FG polysaccharides using ion-exchange. The ratio between neutral to acidic polysaccharides in flaxseed may vary significantly with their origins (Table 2.1) (Ziolkovska 2012, Liu et al. 2016). The neutral polymer constituted 75% of FG mass with molecular weight of approximately 1.2×10^6 g/mol as compared with acidic polysaccharides which consists of AF1 (3.75%, 6.5×10^5 g/mol) and AF2 (21.25%, 1.7×10^4 g/mol) (Warr et al. 2003; Cui, Mazza, and Biliaderis 1994; Qian et al. 2012; Cui, Kenaschuk, and Mazza 1996). The neutral arabinoxylans has a (1→4)-β-D-xylan backbone to which arabinose and galactose side chains are attached at positions 2 and 3 (Cui, Mazza, and Biliaderis 1994). The acidic polysaccharides have a (1→2)-linked α-L-rhamnopyranosyl and (1→4)-linked D-galactopyranosyluronic acid residues with side chains of fucose and galactose. The neutral arabinoxylan polysaccharide is mainly composed of D-xylose, L-arabinose, and D-galactose (6.2:3.5:1), whereas the acidic fraction polysaccharide is mainly composed of L-rhamnose, L-fucose, L-galactose, and D-galacturonic acid (2.6:1:1.4:1.7) (Muralikrishna, Salimath, and Tharanathan 1987). The molecular weight of the neutral polysaccharides fraction is much higher than the acidic fraction, and the different molecular weights will exhibit various rheology properties (Biliaderis and Izydorczyk 2006).

2.7.2. Rheological Properties of Flaxseed Gum

Rheology is the science of flow and deformation of matter, and rheological properties are largely determined by applying a force and recording the resulting flow or deformation. Flaxseed gum is mainly comprised of hydrophilic high MW arabinoxylans and acidic polysaccharides, which are readily hydrated by contact with water, and a dissolved polysaccharide network will form even at low FG concentration (Cui, Mazza, and Biliaderis 1994). FG imparts high viscosity to solution and, therefore, it can be applied in food as a thickener, gelling agent, texture modifier, suspending agent, and stabilizer (Singh et al. 2011). Rheological properties of FG solutions were determined as a function of concentration, temperature, pH, NaCl concentration, and sucrose concentration, and these studies reveal the interaction of FG with other molecules in foods (Liu et al. 2016). FG composition from various cultivars is also important in determining FG solution rheological properties. For examples, Liu et al. (2016) measured steady shear flow behaviour of FG solution over a shear rate range of 0.1 - 100 s^{-1} and a concentration of 0.5 - 3.0% (w/v).

2.7.2.1. Concentration

Flaxseed gum solution (1.00% w/v) from six cultivars all exhibited pseudoplastic or shear-thinning behaviour, which indicates that apparent viscosity decreased with increased shear rate (Liu et al. 2016). Under static conditions in solution, FG polysaccharide molecules are distributed randomly. This irregular order of arrangement affords the maximum flow resistance. When shear force is applied to a solution of FG, the polysaccharide chains are deformed and align with the flow, which decreases slip resistance and apparent viscosity. As greater shear was applied, FG polysaccharide chain entanglement is disrupted, then the rate of forming new entanglement formation and viscosity are reduced (Vardhanabhuti and Ikeda 2006). Warr et al. (2003) observed that FG solution showed shear-thinning flow behaviour at 2.00 % (w/v), and this is caused by hydrogen bond formation and intermolecular associations which form polysaccharide molecular aggregates. With increasing FG concentration viscosity also increased, and CDC Glas FG solutions 1.00 % (w/v) exhibited the highest viscosity (2.984 ± 0.204 Pa·s) of FG solutions prepared from six cultivars while FG solutions prepared from the cultivar CDC Sorrel exhibited the lowest apparent viscosity (0.048 ± 0.001 Pa·s).

FG sugar monomer composition, is cultivar specific and can, in part, determine FG solution rheological properties (Cui, Kenaschuk, and Mazza 1996). High molecular mass neutral polysaccharides imbue solutions with attributes such as high viscosity and typical shear-thinning flow behaviour observed for FG solutions (Goh et al. 2006). Due to the smaller biopolymer average molecular size, AFG solutions showed Newtonian-like flow properties (Cui, Mazza, and Biliaderis 1994). Liu et al. (2016) reported that neutral sugar content of FG from six cultivars varied from

592 ± 84 to 367 ± 27 mg g^{-1} of dried FG, while acidic sugar content of FG varied from 89 ±25 to 181 ±17 mg g^{-1} (Table 2. 1). FG solutions recovered from CDC Bethune had the highest NFG and AFG. CDC Sorrel and Vimy showed the lowest neutral sugar, which resulted in the lowest apparent viscosity (Liu et al. 2016). Vimy and CDC Glas had the lowest acidic sugar content. CDC Glas FG exhibited higher apparent viscosity, which may associate with higher NFG (430 ± 39 mg g^{-1} FG, D-xylose equivalent) and very low AFG (98 ± 18 mg g^{-1} FG D-galacturonic acid equivalent) (Liu et al. 2016).

2.7.2.2. Temperature

Increasing temperature reduces the interaction strength and hydrocolloid network structure of FG solutions, thereby, reducing viscosity (Liu et al. 2016; Garcia-Ochoa and Casas 1992). For FG solutions prepared from FG recovered from six flax cultivars apparent solution viscosities decreased with increased temperature from 15 - 45°C. CDC Glas FG solution (1.0 %, w/v) is temperature sensitive, since at a shear rate 1.0 s^{-1} the viscosity decreased from 6.601 ± 0.341 to 0.330 ± 0.019 Pa·s. as temperature increased from 15 to 45°C. However, FG (1.0 %, w/v) solutions prepared with CDC Sorrel showed smaller temperature sensitivity. Under the same conditions as above, the viscosity decreased from 0.091 ± 0.002 to 0.028 ± 0.009 Pa·s.

2.7.2.3. Salt Addition

For FG solutions, acidic carboxyl groups form a more expanded configuration by increasing intra- and inter-molecular repulsive forces among FG polysaccharide chains. The increase in repulsion increases FG solution viscosity (Lin and Lai 2009). The addition of salt increases ionic strength and screens FG anionic group charges lessening charge repulsion, decreasing molecule expansion and resulting in reduced solution viscosity (Simas-Tosin et al. 2010). FG solutions of CDC Glas had the highest viscosity (3.315 ± 0.438 Pa·s.) with 50 mM NaCl and had the lowest viscosity (1.214 ± 0.042 Pa·s.) after addition of 200 mM NaCl. Compared to FG solutions produced from other cultivars FG solutions prepared from CDC Glas, exhibited lower viscosity as NaCl concentration increased (Liu et al. 2016).

2.7.2.4. Sugar Addition

Sucrose dissolved in hydrocolloid gum solution may change solution rheology by directly interacting with hydrocolloid gum molecules, and increasing viscosity (Yanes, Durán, and Costell 2002). For FG solutions prepared from six cultivars all solutions exhibited increased apparent viscosity with addition of sucrose to the solutions, while CDC Glas showed the greatest increase from 2.98 ± 0.20 to 7.79 ± 1.47 Pa·s (Liu et al. 2016).

2.7.2.5. pH

The pH of the mucilage solution shows a significant effect on the flow behaviour and viscosity of the flaxseed gum. The lowest FG viscosity is observed at pH 2, and viscosity increases with increasing pH until pH 8, where the viscosity is three times its value at pH 2. Further increase of pH make for decreasing of viscosity (Mazza and Biliaderis 1989).

The other study done by Liu et al. (2016) investigated the effect of pH on steady-state shear viscosity of FG solutions prepared from six cultivars. FG solution prepared from CDC Glas increased apparent viscosity with pH from 3.0 to 7.0, while FG solution from other cultivars did not change significantly with varied pH. At low pH (3.0), FG molecular structure in solution exhibits a random coil shape, compared to a rigid rod-like conformation at pH 7.0 and higher. The latter configuration induces more flow resistance and increases apparent viscosity (Goh et al. 2006). Increasing solution pH from 3.0 to 7.0 increases carboxyl group ionization which, in turn, increases repulsive inter- and intramolecular interactions, and further enhances apparent viscosity (Medina-Torres et al. 2000). For the CDC Glas FG solution, the maximum apparent viscosity (3.826 ± 0.910 Pa·s) was observed at pH 5.0. At this pH, the carboxyl group ionization in FG might be maximized (Liu et al. 2016).

Overall, all FG solution exhibited typical shear-thinning behaviour, and the apparent viscosity would change with varied flaxseed cultivars, solution temperature, concentration, pH, NaCl concentration, and sugar concentration. These properties can help with selecting the flaxseed genotype and to control the methodology for FG beverage formulation.

2.8. Physiological Properties and Health Benefits of FG

Except for the functional properties above, the other reason for FG to be a popular food additive is that FG was identified as the active ingredient that gave therapeutic benefit (Liu and Eskin 1998). These findings suggested that flaxseed polysaccharides could be developed as a functional food ingredient.

2.8.1. Antiviral Properties of Flaxseed Gum

Based on recent research reported by Wang et al. (2017), a neutral polysaccharide, called FP-1, was enriched from defatted flaxseed meal using ion-exchange and size exclusion chromatography, FP-1 had a triple-helix conformation, which indicated its potential application for immunomodulation and antiviral effects. FP-1 also inhibited Hepatitis B Virus (HBV) by inhibition of surface antigen (HBsAg) and envelope antigen (HBeAg) expression and by interference with HBV DNA replication (Wang et al. 2017). A number of other polysaccharides also exhibited good antiviral activity against several animal viruses, such as, carrageenan (González, Alarcón, and Carrasco 1987) and sulfated seaweed polysaccharides (Witvrouw and De Clercq 1997), since polysaccharides are a complex group of biological molecules (Aspinall 1983), which affect the growth of animal viruses (Shannon 1984) .

2.8.2. Health benefits of FG

Flaxseed gum was identified as the most likely responsible active ingredient in a diet supplement with partially defatted flaxseed meal, which can level the blood glucose profile in a similar manner to guar gum psyllium, oat gum, and other viscous fibers (Jenkins 1995). The soluble fiber also has the ability to increase the viscosity of the small intestinal contents and delay carbohydrate digestion and absorption, which is believed to reduce the glycemic response (Jenkins et al. 1999; Edwards et al. 1987; Blackburn et al. 1984). The mucilage has also been reported to effectively improve laxation ("Health Effects of Flaxseed Mucilage, Lignans." 1997). FG is also used in medicinal ointments such as pastes which are effective in the treatment of furunculosis, carbunculosis, impetigo, and ecthyma (Aliev 1946). The physicochemical properties of FG are useful in tablet preparation as FG can used as a disintegrant, which will help increasing the rate of drug release (Prajapati et al. 2013).

2.9. Sensory Characteristics of Flaxseed Gum

2.9.1. Sensory Study

During the product development process, many tools could be applied to define the characteristics of the product. These tools include for example, chemical tests, microbiological procedures and the use of physical equipment to determine elasticity, hardness, viscosity, colour intensity and more, but these tests are inadequate to reflect the acceptability or preferences on consumption of the product (Singh-Ackbarali and Maharaj 2014).

Sensory studies measure the human senses including taste, texture, appearance, and smell in a controlled environment. The sensory evaluation is essential for developing new products and assessing product characteristics, which can help to ensure consumer satisfaction and achieve market success ("Sensory Research of Food - Nutrition and Dietetics" n.d.). For food and beverage products, the main concept for sensory analyses is to integrate with marketing, such that a person's perception on sensory quality is the priority, other than the real taste evaluations (Singh-Ackbarali and Maharaj 2014). To ensure product success, it is important to understand what consumers think they are tasting as compared with what they really taste (Lesser 1983).

The methods of sensory evaluation generally can be divided into two categories including a panelist sensory evaluation and a consumer acceptance study. Panelist sensory evaluation can be achieved through descriptive analysis, which contains "free choice profiling" and quantitative analysis (Stone and Sidel 1998). Descriptive analysis generally involves in-depth sensory testing which can assess the suitability of certain applied compounds in the new products, and how the new compounds will affect overall quality. Any problems with quality can be solved before using the solution in a consumer acceptance study (Khan et al. 2015). All the panelists need to be trained by providing them with several samples similar to the target products. Initial description process is based on "free choice profiling", which relevant quality attributes like colour (red) or appearance (glossy), can be written by the panelists. Subsequently, a suitable score card could be designed according to these descriptors, and quantitative descriptive analysis is followed (Stone and Sidel 1998). The evaluation should be conducted under white fluorescent light. The suitable score card is developed based on the results of "free-choice profiling" method selecting suitable terminology. The samples should be presented in small cups coded with 3-digit random numbers to trained panelists. Panelists are asked to mark on a scale to indicate the intensity of each attributed listed on the score. The scores given for all the attributes for each sample then is tabulated. The mean value is calculated for each attribute of the sample to represent the panelist's judgment about the sensory quality of the product. Lastly, the score is depicted graphically as "sensory profile".

The second method used is consumer acceptance study which is applied to testing overall acceptance of the product with a larger consumer group who are untrained. Selection is based on their health condition (to ensure they are not having any defects in sensory perception), general sensitivity and their prior experience in sensory evaluation of food products. A scale sheets varied from "like very much" to "dislike very much" with "neither like nor dislike" as mid-point is carried out for consumer acceptance study.

In the sensory study done by Aliani et al. (2012), the bagel product with flax addition was evaluated with both descriptive test and consumer acceptance study. Sensory studies of cookies with flaxseed incorporation was conducted by a group of semi-trained members using hedonic tests to evaluate parameters such as colour, taste, texture, and overall acceptability (Jain and Ganorkar 2014). In another study conducted by Adinsi et al. (2015), the consumer acceptability of a beverage "gowe" made from malted and fermented cereal was evaluated on panelists like for appearance, tastes, and overall liking using a 9-point hedonic scale from "Dislike Extremely" to "Like Extremely".

2.9.2. Sensory Characteristics of Flaxseed Gum

All the physicochemical and functional properties described above suggest that FG has potential for use as an industrial food additive. Furthermore, texture and sensory properties are major standards for consumer acceptability of food products (Kaewmanee et al. 2014). A sensory profile of FG solutions (0.1% in deionized water) from seven Italian cultivars was determined by Kaewmanee et al (2014). Most FG solutions from the cultivars Valoal, Linoal, Merlin and Natural were flavourless, while Kaolin, Festival, and Solal had slight (less than 2 points on a 10-point category scale) bitter, sweet, and umami flavours (Figure 2.2). The mild taste associated with FG will have little impact on the natural taste and flavour of a food product, which makes usage of FG as a food additive achievable.

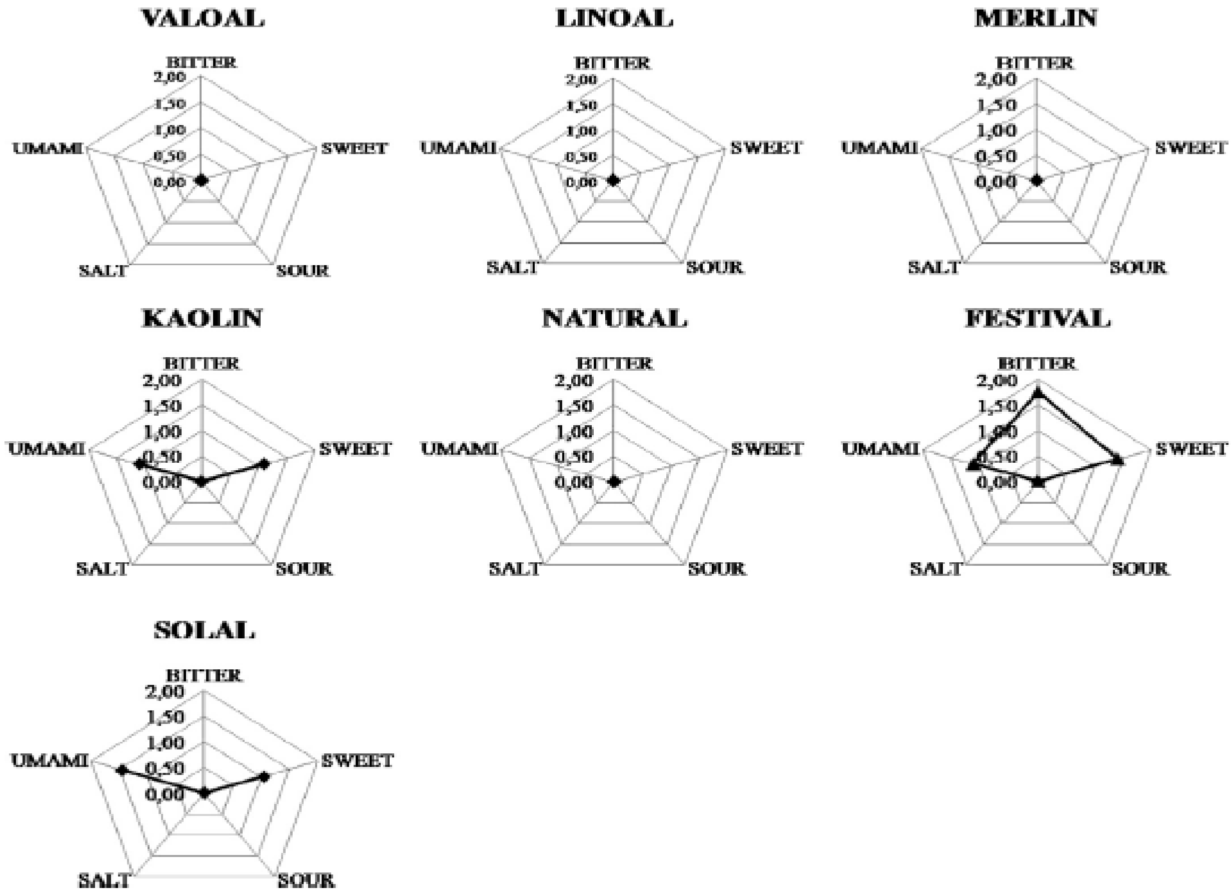


Figure 2.2 The taste profile of flaxseed gum (FG) solutions from seven Italian flax cultivars (Figure taken from Kaewmanee et al. 2014).

2.10. Utilization of Flaxseed Gum as Additives in Food Products

Flaxseed gum properties, like those described above, provide information that can lead to better utilization as additives in food, beverage, and pharmaceutical products. Also, FG has attracted attention due to its beneficial effects in mitigating diabetes, heart disease, and colorectal cancer (Tarpila et al. 2005; Cunnane et al. 1993). As an emulsion stabilizer, FG was added to whey protein isolates and soybean protein isolates to improve emulsion stability (Wang et al. 2011; Khalloufi et al. 2009). Flaxseed gum also stabilizes cloudy carrot juice and salad dressing due to its macromolecular steric repulsion and emulsion forming properties (Qin, Xu, and Zhang 2005; Stewart and Mazza 2000). In meat products, FG was used owing to the desired interaction between FG with meat protein (Chen, Xu, and Wang 2007). In addition, meat emulsions extended with flaxseed mucilage resulted in reducing cooking loss and decrease firmness (Dev and Quensel 1988). Except for interactions of FG and proteins, FG was also shown to interact with maize starch in food systems to control the texture and improve food product stability (Wang et al. 2008). Furthermore, FG is an egg white substitute in bakery and ice cream, where it functions as a stabilizer and texturizer (Singh et al. 2011; Xu and Sun 2008; Cui 2005; Liu, He, and Mu 2005).

2.11. Summary of Literature Review

In the previous literature, the nutrients, physiochemical, and potential functional properties of FG were explained, which indicated the possibility of applying FG into food products. In this study, we investigated FG utility as a bioactive ingredient for beverages that gave acceptable sensory characteristics that helped with consumer acceptance. The appearance, aroma, texture, and taste intensity of FG were also investigated to optimize both the sensory characteristics and acceptance of FG beverage. Also, the physicochemical properties of FG product were analyzed.

3. MATERIALS AND METHOD

3.1. Materials

Three Canadian flaxseed cultivars (CDC Bethune, CDC Glas, and CDC Sorrel, Figure 3.1) were used in this study. CDC Glas was harvested in 2015, from Shewchuk Seed, whilst CDC Bethune and CDC Sorrel were provided by Allan Seeds in 2013 and 2015, respectively. All selected flaxseed varieties were oil seed cultivars with brown colour seed coats. The seed was kept in a desiccator at room temperature until used.

Figure 3.1 Whole flaxseed of three Canadian flaxseed cultivars (From left to right: CDC Glas, CDC Bethune, CDC Sorrel).

3.2. Reagents and chemicals

Food grade chemicals; dextrose, potassium citrate, sodium citrate, and sodium chloride were purchased from Spectrum Chemical Mfg. CORP (Gardena, CA, USA). Anhydrous undenatured beverage ethanol was obtained from Greenfield Global Inc. (Mississauga, ON, Canada). Resorcinol and D-xylose were purchased from Sigma-Aldrich Canada Ltd. (Oakville, ON, Canada). Concentrated sulphuric acid (≥96%, w/w) was purchased from EMD Millipore

Corporation (Burlington, MA, USA). Pure orange extract (Club House, London, ON, Canada) was obtained from a local supermarket (Sobeys, Saskatoon, SK, Canada). All other reagents were analytical grade.

3.3. FG Extraction

3.3.1. Seed Treatment

To study the differences among mucilage extracts from whole flaxseed and flaxseed meal, seeds from each cultivar were divided into two extraction groups. The first group of FG was extracted directly from whole flaxseed by washing the seed in distilled water for 1 min at approximately 22°C to remove surface particulate matter and dust. The second group of flaxseed was dry milled using a Glen Mills Type C/11/1 Tabletop Disc Mill (Glen Mills Inc., Clifton, NJ, USA), at room temperature using setting #4. All ground seed were stored at -20°C until further processing.

3.3.2. FG Extraction

Flaxseed mucilage was extracted following a slightly modified method detailed in Wang et al. (2009). Briefly, distilled water was preheated to 60°C or 80°C, then whole flaxseed or flaxseed meal was added at a ratio of 10:1 (water to flaxseed) and gently stirred (300 rpm) for 2 h using a magnetic stir bar. The extracted FG was separated from whole flaxseed or flaxseed meal by filtering the solution through multiple layers of cheese cloth and further precipitated using anhydrous undenatured ethanol. The precipitate was collected through vacuum filtration, and the ethanol layer was removed by air-drying the samples overnight. Lastly, aqueous FG precipitates were then lyophilized using a LABCONCO freeze-dryer (Kansas City, MO, USA). The dried FG samples were kept in a desiccator at room temperature for subsequent studies. All extractions were conducted in triplicate. FG yields were calculated and presented as mean ± standard deviation (SD).

3.4. Formulation

3.4.1. FG Solution Preparation

Dried FG samples were weighed and dissolved in deionized water (2.00%, w/v), with gentle stirring (300 rpm) for 2 h, at room temperature. Subsequent, FG polymer dispersion was kept at 4°C for 24 h to ensure completion of the hydration process. Air bubbles were removed from the FG dispersion by centrifugation at 2500 *x g* for 2 min (Liu et al. 2016) and the FG supernatant fractions were collected for further analyses.

3.4.2. Oral Rehydration Solution Preparation

The oral rehydration solution model system was prepared with 2500 mg of dextrose ($C_6H_{12}O_6$), 205 mg of sodium chloride (NaCl), 204 mg of potassium citrate ($C_6H_5K_3O_7$), and 86 mg of sodium citrate ($Na_3C_6H_5O_7$) ("Pedialyte - Uses, Side Effects, Interactions - MedBroadcast.com" n.d.). Solutes were mixed with distilled water (1 L) at room temperature for 5 min, then heated to 70°C for incorporation and cooled back to room temperature. The solution was stored at 4°C until further analyses.

3.4.3. Beverage Formulation

The final mixture of the FG beverage, was prepared by mixing FG solutions with the oral rehydration solutions. This mixture was then heated between 70 to 75°C for 3 min with constant agitation. Flavor compounds, such as pure orange extract, were also added to the solution. The final concentration of FG in the mixture was 0.50% and 1.00% (w/v). The FG beverages were stored in the fridge for further analysis.

3.5. Physicochemical Properties

3.5.1. Determination of Transmittance

The transmittance of the FG beverage was determined by optical density (OD) measurements at 420 nm using a Genesys 10S UV-vis spectrophotometer (Thermo Scientific, Madison, WI, USA). Distilled water was used as the blank and readings were conducted in triplicate and given as a mean value ± SD.

3.5.2. Determination of pH

FG beverage pH was determined using an Orion 4 Star pH meter (Thermo Scientific, Madison, WI, USA), and readings were taken in triplicate and given as mean value ± SD

3.5.3. Determination of neutral sugar content

The neutral sugar content of FG was conducted using spectrophotometric analyses based on a modified methodology incorporating methods from the AOAC Method 44.1.30, Monsigny *et al.* (1988) and Liu *et al.* (2016). Briefly, small aliquots (0.4 mL) of FG beverage solution (0.50% and 1.00%, w/v in water) were mixed with 0.4 mL of resorcinol solution ($C_6H_6O_2$) **(**6.0 mg mL^{-1}), followed by the addition of sulphuric acid (2 mL; 75%, v/v). Resorcinol solution was stored at 4°C in the dark for up to 1 month. The 75% sulphuric acid was kept in the dark at RT for up to 3 weeks. Mixtures were shaken by a vortex mixer for 30 s. The OD for the sample mixtures, were measured at 490 nm using a Genesys 10S UV-vis spectrophotometer (Thermo Scientific, Madison, WI, USA). Blanks were prepared using deionized water to replace FG solution following the same procedure and the calibration curve (0.2 - 8.0 mg mL^{-1}) was prepared using D-xylose ($C_5H_{10}O_5$) solution. The final FG neutral sugar concentration is expressed as milligrams of D-xylose equivalents per gram of the mucilage powder. All measurements were taken in triplicate, and results were presented as mean ± SD.

3.5.4. Determination of viscosity

Dynamic viscosity of FG beverage solution (0.50% and 1.00%, w/v in water) was measured using an AR G2 rheometer (TA Instruments Ltd., Crawley, UK. Figure 3.2). Beverage solutions (2.0 mL FG) were loaded onto the bottom plate of the rheometer, and the samples were equilibrated for 2 min before each measurement. A 60 mm acrylic cone plate geometry (1.969°) was used with a 1.0 μm gap. The rheometer temperature (25 °C) was controlled by a water bath connected to a Peltier System (TA Instruments Ltd., Crawley, UK). The viscosity was measured under a continuous shear rate over a shear rate range between 0.01 to 1000 per second. Samples were prepared the day before measurement and stored in refrigeration. To determine the apparent viscosity, the Power law model (Eq. 3.1) was applied to fit each FG beverage solution dynamic flow curve. The experiments were conducted in triplicate. The results were presented as mean values. Data analysis was conducted using the TA Rheology TRIOS Data Analysis Software V4.4.0 (TA Instruments Ltd., Crawley, UK).

$$\boldsymbol{\eta = k\dot{\gamma}^{n-1}} \tag{3.1}$$

where k is the consistency coefficient ($Pa \cdot s^n$), $\dot{\gamma}$ is the shear rate (s^{-1}), and n is the fluid behaviour index.

Figure 3.2 AR G2 rheometer for rheological analysis (TA Instruments Ltd., Crawley, UK).

3.6. Sensory analysis

Sensory characteristics of FG beverage samples were evaluated by a group of individuals including students and staff members of the University of Saskatchewan. These participants evaluated FG beverage samples for the following attributes: colour desirability, odour/smell, texture/mouth feel, taste/flavour intensity, after-taste intensity, and product acceptability. A pre-screening questionnaire was conducted to determine any food allergies or concerns regarding to the sensory study. Panelists were selected based on their perception of basic tastes and familiarity with the product. Ten participants (six women and four men) partook in the final evaluation. Participants were between the ages of 24 to 40 years old and consumed oral rehydration solutions occasionally. Sensory attributes like colour, odour, texture, taste intensity, after-taste intensity, and overall product acceptability for all samples were assessed using an eight-point hedonic scale. The scale definitions, used for rating the samples, included: “extremely undesirable”, “very undesirable”, “moderately undesirable”, “slightly undesirable”, “slightly desirable”, “moderately desirable”, “very desirable” and “extremely desirable” (Table 3.1).

Table 3.1 The 8-point hedonic scale score sheet.

Colour Desirability

Extremely Undesirable (1)	Very Undesirable (2)	Moderately Undesirable (3)	Slightly Undesirable (4)	Slightly Desirable (5)	Moderately Desirable (6)	Very Desirable (7)	Extremely Desirable (8)

Odour/ Smell

Extremely Intense (1)	Very Intense (2)	Moderately Intense (3)	Slightly Intense (4)	Slightly Bland (5)	Moderately Bland (6)	Very Bland (7)	Extremely Bland (8)

Texture/ Mouthfeel

Extremely Sticky (1)	Very Sticky (2)	Moderately Sticky (3)	Slightly Sticky (4)	Slightly Slippery (5)	Moderately Slippery (6)	Very Slippery (7)	Extremely Slippery (8)

Taste/ Flavour Intensity (Salty, Sweetness, and sour intensities)

Extremely Intense (1)	Very Intense (2)	Moderately Intense (3)	Slightly Intense (4)	Slightly Bland (5)	Moderately Bland (6)	Very Bland (7)	Extremely Bland (8)

After Taste Intensity

Extremely Intense (1)	Very Intense (2)	Moderately Intense (3)	Slightly Intense (4)	Slightly Bland (5)	Moderately Bland (6)	Very Bland (7)	Extremely Bland (8)

Product Acceptability

Extremely Unacceptable (1)	Very Unacceptable (2)	Moderately Unacceptable (3)	Slightly Unacceptable (4)	Slightly Acceptable (5)	Moderately Acceptable (6)	Very Acceptable (7)	Extremely Acceptable (8)

3.6.1. Training Sessions

During the first two training sessions, participants were familiarized with FG beverage samples, and were also provided with several samples of beverage and food similar to FG beverages for demonstration purposes. In addition, method of scoring, evaluation techniques, and rating scale used to rate the select sensory attributes were discussed with all panelists, during these training sessions, to ensure standardization of the results (Table 4.5)

3.6.2. Evaluation Sessions

FG solution and oral rehydration solution were prepared daily, and after preparation, the FG was stored at 4°C for a maximum of 16 hours to meet consumption for the next day. During each session, each panelist would receive a sample tray (Figure 3.3). On the sample tray, approximately 9 samples were presented at room temperature in an identical plastic portion cup (1.5 oz), containing approximately 30 mL of sample, and coded with three random digit numbers in a randomized order under white light. Distilled water and unsalted crackers were also provided to rinse the panelists mouth and clean their palate, respectively, before and between evaluations for each formulation. The sessions were performed in the afternoon (14:00 - 16:30) in a standardized panel test room with separate booths for each assessor to provide a serene atmosphere and to avoid disturbance and influence among panelists. All samples were scored in triplicate within four consecutive days by each of the ten participants. Mean scores for each attribute were calculated for the comparison of the samples.

The research was reviewed and approved by the University of Saskatchewan Research Ethics Board on Human Ethics subjects (Appendix B). All panelists gave written informed consent to participate in the study.

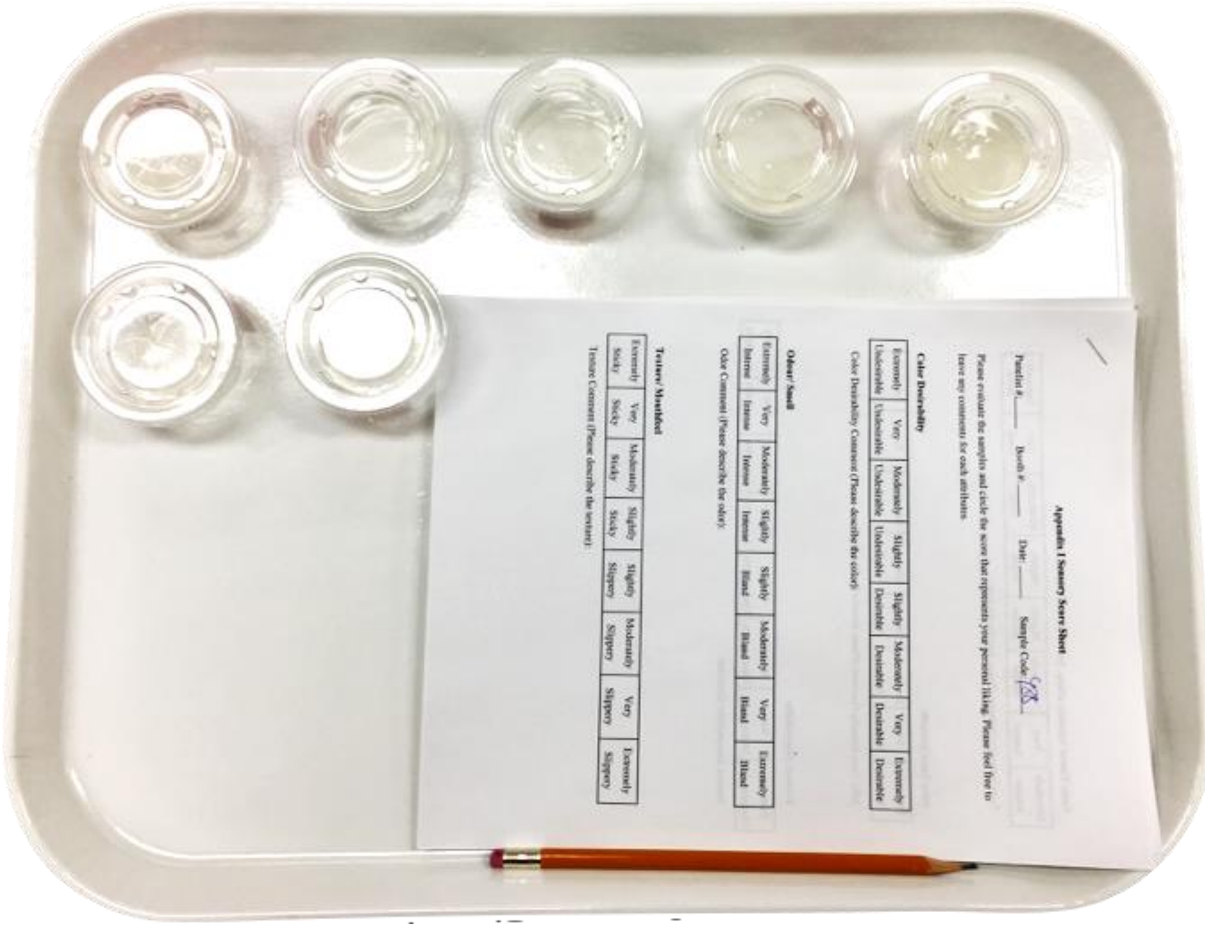


Figure 3.3 Example of sample tray during flaxseed gum (FG) beverage study.

3.7. Statistical analysis

All measurements were performed in triplicate, and reported as the mean ± SD, except for the data used for preparing the flow curves. One-way analysis of variance (ANOVA) was performed to test the Between-Subjects effect. All statistical studies were conducted at a 95% confidence interval using IBM's SPSS Statistical Package (version 1.0.0.1131; SPSS Inc., Chicago, IL, USA). Post hoc analysis, Least Significant Difference (LSD), was performed where statistical differences were present between pairs of means.

4. RESULTS AND DISCUSSION

4.1. Effect of Seed Treatment

The first set of analyses examined the impact of seed treatment on the appearance of FG beverage. Whole and milled flaxseed were both used for FG extraction at the temperature of 60°C, and the produced gums was used for FG beverage formulation. The most striking observation that emerged from the final products were that FG beverage made from flaxseed meal extracted gum was extraordinarily oily and foggy.

To compare the difference between FG extracted with whole/milled seed, transmittance was assessed. The average optical density of FG beverage extracted from whole seed and milled seed at both 0.50% and 1.00% (w/v) were compared in Table 4.1. It is apparent from this table that the optical density of FG beverage prepared from milled seed is much higher than FG beverage made with whole seed for all cultivars and concentration. For the 0.50% (w/v) FG beverage made from milled seed, the optical density varied from 1.4 (CDC Bethune and CDC Sorrel) to 1.58 (CDC Glas), while the 1.00% FG beverage made from milled seed presented substantially higher optical density from 2.08 (CDC Sorrel) to 2.96 (CDC Bethune).

These results support previous research on the differences of FG extracted from various raw materials, whole seed, or flaxseed meal. The high optical density of the FG beverage prepared from milled seed may due to the protein and tannin pigment that exist in the mucilage (Biliaderis and Izydorczyk 2006; Fedeniuk and Biliaderis 1994; Bhatty 1993; Tomoda and Asami 1950). More importantly, the process of separating gum from flaxseed meal was distinctly time-consuming. Taken together, these observations and results suggest that milling flaxseed before gum extraction is not practical for developing an oral rehydration solution with FG, and therefore was excluded from further analysis.

Table 4.1 The optical density (OD) of flaxseed gum (FG) beverage made with FG extracted from both whole and milled seed at 60°C with 0.50% and 1.00% (w/v) concentration.

Cultivar	Seed Treatment	OD	
		0.50%	1.00%
CDC Glas	Milled	1.58 ± 0.74	2.80 ± 2.03
	Whole	0.31 ± 0.01	1.49 ± 0.06
CDC Bethune	Milled	1.40 ± 0.06	2.96 ± 0.05
	Whole	0.27 ± 0.02	1.36 ± 0.01
CDC Sorrel	Milled	1.40 ± 0.50	2.08 ± 1.59
	Whole	0.36 ± 0.00	1.82 ± 0.02

4.2. FG Extraction Yield

Before proceeding further with examining the physicochemical properties of the FG beverage preparations, it was essential to determine FG extraction yield for three flaxseed cultivars used, since the extraction yield is an influential parameter for measuring the economic viability of product (Liu et al. 2016). In this study, FG yields of three cultivars (CDC Glas, CDC Bethune, and CDC Sorrel) of flaxseed extracted with distilled water at both 60 and 80°C are shown in Table 4.2. FG yields are expressed as g FG/100 g flaxseed. Yields of FG ranged from 7.23 g/100 g flaxseed (CDC Bethune extracted at 60°C) to 12.57 g/100 g flaxseed (CDC Glas extracted at 80°C). As observed from the table below, the CDC Glas had the highest FG yield regardless of extraction temperature (60°C or 80°C), whereas CDC Bethune produced the lowest yield. The table also revealed that when the extraction temperature was increased from 60°C to 80°C, FG yield also increased for all three flaxseed cultivars.

This finding confirms that extraction temperature significantly impacts yield of FG, and with higher extraction temperature, the gum yield would increase. The similar trend for FG yield could be found in previous studies (Cui, Kenaschuk, and Mazza 1996; Cui et al. 1994). This trend may due to the extraction yield of water soluble protein, which is consequently increased with higher extraction temperature and will contribute to greater FG yield (Kaushik et al. 2017). Also, the result of highest FG yield of CDC Glas among three cultivars is in agreement with Liu et al. (2016) in their study of gum variation from six Canadian flaxseed cultivars, and FG yield is a function of cultivar (Kaewmanee et al. 2014). Also, in the Liu et al. (2016) study, CDC Glas, CDC Bethune, and CDC Sorrel extracted at 60°C had a yield of 13.62, 9.33, and 12.71 g/100g seeds, respectively, which is higher than yields reported in the current study. This may due to environmental factors, such as climatic conditions and crop age (Pavlov et al. 2014; Diederichsen, Raney, and Duguid 2006), since the cultivars are the same. The other reason for the difference in yields is the various extraction conditions employed (Wang et al. 2010). In Kaushik et al (2016) study, they evaluated the extraction temperature, and found it to significantly affect the yield of FG. Thus, using CDC Glas and extracting at 80°C, as done in this study, would likely have the greatest economic viability.

Table 4.2 Flaxseed gum (FG) yield extracted from whole seed of three flax cultivars at both 60°C and 80°C. Values are provided as mean ± SD. Different superscripts in the same column indicate statistically significant differences among flaxseed cultivar ($P < 0.05$).

Cultivar	**Yield (%)**	
	60°C	**80°C**
CDC Glas	**11.56 ± 1.32^{a}**	**12.57 ± 0.93^{a}**
CDC Sorrel	**9.60 ± 0.46^{b}**	**11.97 ± 0.88^{b}**
CDC Bethune	**7.23 ± 0.16^{c}**	**10.02 ± 0.21^{c}**

4.3. pH value

Physicochemical properties are used to observe and describe FG beverage products. For drinking products, appearance or colour, texture, and whether the products have a sour taste are essential values to report. The pH of FG beverage is presented in Table 4.3 (a) and (b). FG beverages prepared with 0.50% FG exhibited pH values between 6.67 and 7.09, whereas the range was 5.82 to 6.78 for FG beverages with 1.00% (w/v) concentration. Three flaxseed cultivars had significant differences in pH values ($p < 0.05$), but no significant differences were observed for the cultivar group of 1.00% (w/v) FG beverage extracted at 80°C. Among the three cultivars, CDC Glas illustrated the lowest pH value, while CDC Sorrel at 60°C and CDC Bethune at 80°C showed the highest pH values of 6.91 and 7.09, respectively. Extraction temperature also affected beverage pH, which increased when the extraction temperature rose. Conversely, the pH decreased with higher FG concentration. Lower pH values from reduced extraction temperatures and increased FG concentration may be due to a greater content of galacturonic acid, as part of FG hydrocolloid, that exists in the sample (Cui, Mazza, and Biliaderis 1994).

In the market, the pH of commercial nonalcoholic/nondairy beverage ranges from 2.1 (lime juice concentrate) to 7.4 (spring water) (Seow and Thong 2005). The pH is the primary determinant of a beverage's erosive potential to dental health (Reddy et al. 2016), and a weak acid composition of the beverage is responsible for immediate dissolution and softening of surface tooth structure (Shellis, Featherstone, and Lussi 2014; Seow and Thong 2005). The regular consumption of acidic beverages is a developing problem and considered to be a critical cause of dental erosion observed among children and adolescents (Carvalho et al. 2014; Murakami et al. 2011; Lussi and Jaeggi 2006). A pH range from 3.0 to 3.99 is considered erosive, while a beverage with pH greater than 4.0 is considered to minimally erosive (Larsen and Nyvad 1999). Overall, all FG beverage samples produced had a neutral pH value which is close to natural water, and thus is unlikely to bring damage or only minimum damage to children and adolescents.

Table 4.3 Optical density (OD), pH, and neutral sugar of 0.50% (a) and 1.00% (b) flaxseed gum (FG) beverage made with FG extracted from whole seed at 60°C or 80°C with varied flaxseed cultivars. Values are provided as mean ± SD. Different superscripts in the same column indicate significant differences among flaxseed cultivar ($P < 0.05$).

(a)

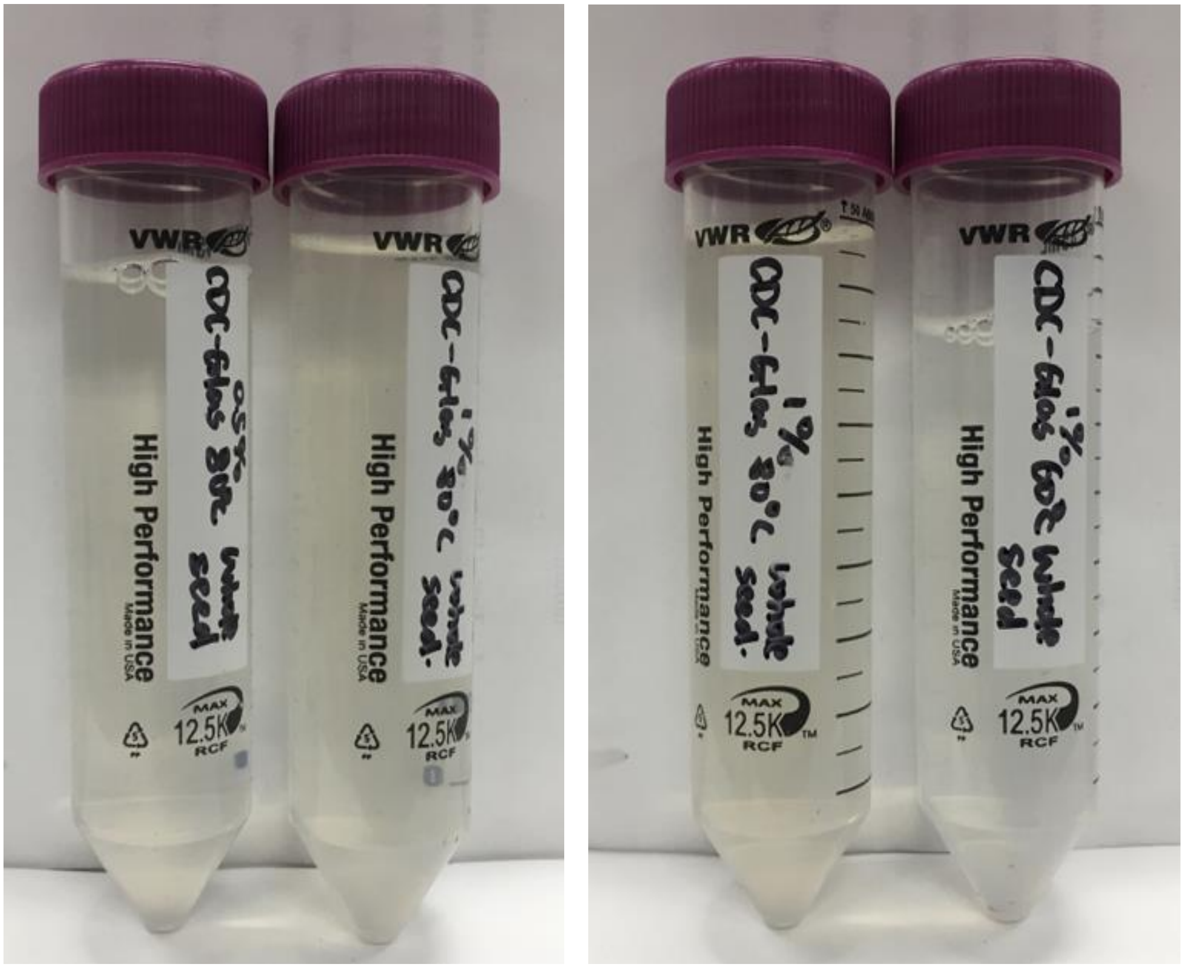
Cultivar	0.50%					
	OD		pH		Neutral Sugar (mg g^{-1} FG)	
	60ºC	80ºC	60ºC	80ºC	60ºC	80ºC
CDC Glas	0.31 ± 0.01^{b}	0.18 ± 0.01^{b}	6.67 ± 0.03^{c}	7.00 ± 0.01^{a}	78 ± 38^{b}	121 ± 37^{ab}
CDC Bethune	0.27 ± 0.02^{b}	0.18 ± 0.01^{b}	6.87 ± 0.01^{b}	7.09 ± 0.01^{b}	138 ± 22^{a}	163 ± 36^{a}
CDC Sorrel	0.36 ± 0.01^{a}	0.38 ± 0.01^{a}	6.91 ± 0.01^{a}	6.99 ± 0.01^{c}	58 ± 10^{b}	88 ± 33^{b}

(b)

Cultivar	1.00%					
	OD		pH		Neutral Sugar (mg g^{-1} FG)	
	60ºC	80ºC	60ºC	80ºC	60ºC	80ºC
CDC Glas	1.49 ± 0.11^{b}	0.93 ± 0.06^{b}	5.82 ± 0.01^{c}	6.63 ± 0.05^{b}	261 ± 25^{b}	343 ± 13^{b}
CDC Bethune	1.36 ± 0.01^{b}	0.88 ± 0.04^{b}	6.29 ± 0.01^{b}	6.78 ± 0.01^{a}	382 ± 9^{a}	474 ± 35^{a}
CDC Sorrel	1.82 ± 0.00^{a}	2.02 ± 0.04^{a}	6.35 ± 0.04^{a}	6.56 ± 0.04^{b}	201 ± 20^{b}	385 ± 19^{b}

4.4. Transmittance

The appearance of a food product has considerable influence on customer selection, which will affect the willingness of a customer to accept a product (Imram 1999). To compare the appearance of FG beverages, determination of Transmittance was conducted by UV-Vis spectrophotometry at 420 nm, and results are reported in Table 4.3 (a) and (b). For the 0.50% (w/v) FG beverage, the optical density varied from 0.18 (CDC Glas and CDC Bethune extracted at 80°C) to 0.38 (CDC Sorrel extracted at 80°C). Compared with 0.50% (w/v) FG beverage, the 1.00% FG beverage presented substantially higher optical density from 0.88 (CDC Bethune extracted at 80°C) to 2.02 (CDC Sorrel extracted at 80°C). The cultivars CDC Bethune and CDC Glas had a lower optical density, which would provide a better product appearance. This may due to the protein content differences, which is partly determined by flaxseed genotype (Kaewmanee et al. 2014; Liu et al. 2016). The protein content of FG from, CDC Bethune, CDC Glas, and CDC Sorrel are 56.6, 64.9, and 87.3 g/100 g seeds, respectively (Liu et al. 2016). In this study, CDC Sorrel was determined to be the cultivar with highest protein content, and presented the highest optical density. In terms of extraction temperature as a factor, most FG extracted at 80°C exhibited a more acceptable appearance, except for CDC Sorrel (Figure 4.1). Although increasing extraction temperature will lead to higher protein content, the reason for an improved appearance with FG extracted at 80°C may be due to protein denaturing under higher extraction temperatures (Kaushik et al. 2017).



(a) **(b)**

Figure 4.1 Flaxseed gum (FG) beverage. (a) 0.50% and 1.00% CDC Glas extracted at 80°C (left to right); and (b) 1.00% CDC Glas extracted at 80°C and 60°C (left to right).

4.5. Neutral Sugar Content

Measurement of the neutral sugar content of FG beverage is important as it would highly impact other physicochemical and functional properties, such as rheological properties and antiviral properties. As mentioned in the literature, the antiviral effect of FG depends on the neutral sugar, as higher neutral sugar contents would provide greater benefits to the FG beverage (Wang et al. 2018). In this study, the neutral sugar content was determined by a spectrophotometer, using

FG beverage mixed with resorcinol ($C_6H_6O_2$) and sulphuric acid (H_2SO_4). A calibration curve ($y=0.2372x + 0.0495$, $R^2= 0.9942$) was generated using D-xylose ($C_5H_{10}O_5$) solution (0.2 - 8.0 mg mL^{-1}) as a representative neutral sugar.

The neutral sugar content of various formulations of FG beverages is compared in Table 4.3 (a) and (b). The neutral sugar content varied from 58 ± 10 to 163 ± 36 mg g^{-1} dried FG for 0.50% (w/v) FG beverage. FG derived from CDC Bethune contained the highest neutral sugar content (138 ± 22 and 163 ± 36 mg g^{-1} dried FG, at 60 and 80°C, respectively) amongst all three cultivars. For the 1.00% (w/v) FG beverage, the neutral sugar content was observed to be between 201 ± 20 to 474 ± 35 mg g^{-1} dried FG. CDC Bethune had the highest neutral sugar content (474 ± 35 mg g^{-1} dried FG) when the FG was produced at 80°C. On the contrary, FG extracted at 60°C from CDC Sorrel contained the least amount of neutral sugar (201 ± 20 mg g^{-1} dried FG). Table 4.3 (a) and (b) also indicate that by increasing the extraction temperature from 60 to 80°C, the neutral sugar content in FG beverage would increase 1.18 to 1.92 times. This increase is probably due to the enhanced extraction of arabinose and galactose with higher extraction temperatures, as stated by Kaushik et al. (2017). Another finding from Table 4.3 (a) and (b) is that the neutral sugar content rose from 2.77 to 4.38 times when FG concentration increased from 0.50% to 1.00% (w/v).

These findings on genotypic differences in neutral sugar content among the three flaxseed cultivars is consistent with Liu et al. (2016), who also found that CDC Bethune contained the highest neutral sugar content, followed by CDC Glas, and finally CDC Sorrel, which had the lowest. This study is also in accordance with previous studies which showed neutral sugar content varied substantially between flaxseed cultivars (Kaewmanee et al. 2014; Izydorczyk, Cui, and Wang 2005).

4.6. Rheological Properties

The broad differences in chemical composition between flaxseed cultivars allows some FG to show strong rheological properties, for example, the formation of gel, whereas FG from other cultivars behaves like a viscoelastic fluid (Cui and Mazza 1997). In this study, the steady shear flow behaviour of FG beverage was studied over a shear rate range of 0.1 - 1000 s^{-1} and a concentration at 0.50% and 1.00% (w/v). When the shear rate at very low value (< 0.1 or >1000), FG samples exhibited at Newtonian flow. The effects of flaxseed cultivars, extraction temperature, and FG concentration on FG beverage rheological properties were investigated.

Table 4.4 Power law coefficients of fits for rheological measurements of (a) 0.50% and (b) 1.00% flaxseed gum (FG) beverage solution as a function of extraction temperature.

(a)

0.50%				
Cultivar	**Treatment**	**Parameter**		
	Extraction Temperature (°C)	***n***	***k* (Pa·s^n)**	**R^2**
CDC Glas	**60**	**0.453**	**1.496**	**0.994**
	80	**0.446**	**1.189**	**0.990**
CDC Bethune	**60**	**0.564**	**0.671**	**0.996**
	80	**0.597**	**0.527**	**0.998**
CDC Sorrel	**60**	**0.563**	**0.566**	**0.982**
	80	**0.592**	**0.517**	**0.997**

(b)

1.00%				
Cultivar	**Treatment**	**Parameter**		
	Extraction Temperature (°C)	**n**	**k (Pa·s^n)**	**R^2**
CDC Glas	**60**	**0.142**	**5.806**	**0.984**
	80	**0.208**	**4.677**	**0.975**
CDC Bethune	**60**	**0.449**	**1.458**	**0.994**
	80	**0.491**	**1.338**	**0.998**
CDC Sorrel	**60**	**0.451**	**1.327**	**0.993**
	80	**0.478**	**1.254**	**0.986**

4.6.1. Flaxseed cultivars effects

The steady-state shear flow curves of 1.00% (w/v) FG beverage prepared from three flaxseed cultivars are shown in Figure 4.2. All three FG beverages exhibited pseudoplastic or shear-thinning behaviour, where the viscosity of FG beverage solution decreased with increased shear rate. FG beverage prepared with CDC Glas had the highest apparent viscosity, while CDC Bethune and CDC Sorrel had relatively lower apparent viscosities.

The *k* and *n* coefficients (Table 4.4) were obtained by fitting the Power law model to flow curves of FG beverages (0.50% and 1.00%, w/v). The least squares fits of flow curves to Eq. 3.1 were illustrated by lines in Figure 4.2. The coefficient of determination (R^2) was 0.975 and higher for all tested FG beverage, which supports the use of the Power law model to describe the rheological properties of FG beverage solution as a function of shear rate in this study. From Table 4.4 (a) and (b), at the same FG concentration, FG extracted from CDC Glas had the highest *k* value for both extraction temperature and FG concentration, which indicated the highest viscosity and pseudoplasticity compared to CDC Bethune and CDC Sorrel. The opposite trend was observed for *n* coefficients, as CDC Glas exhibited the lowest *n* value, whereas CDC Bethune and CDC Sorrel had higher values. The *n* value is the fluid behaviour index, which describes the type of fluids departure from Newtonian flow (Chhinnan, McWatters, and Rao 1985). For n=1, the solution is a Newtonian flow, whereas n>1 means the solution is a dilatant fluid, and at n<1 the solution is a pseudoplastic fluid, indicating apparent decreased viscosity with increased shear rate. This applied for all FG beverage formulations in this study (Table 4.4 (a) and (b)). The shear-thinning flow behaviour of FG was attributed largely to the high molecular mass of neutral polysaccharides (arabinoxylans) (Goh et al. 2006). These results are in agreement with those obtained by Liu et al (2016), where CDC Glas exhibited the highest apparent viscosity and CDC Sorrel had the lowest apparent viscosity.

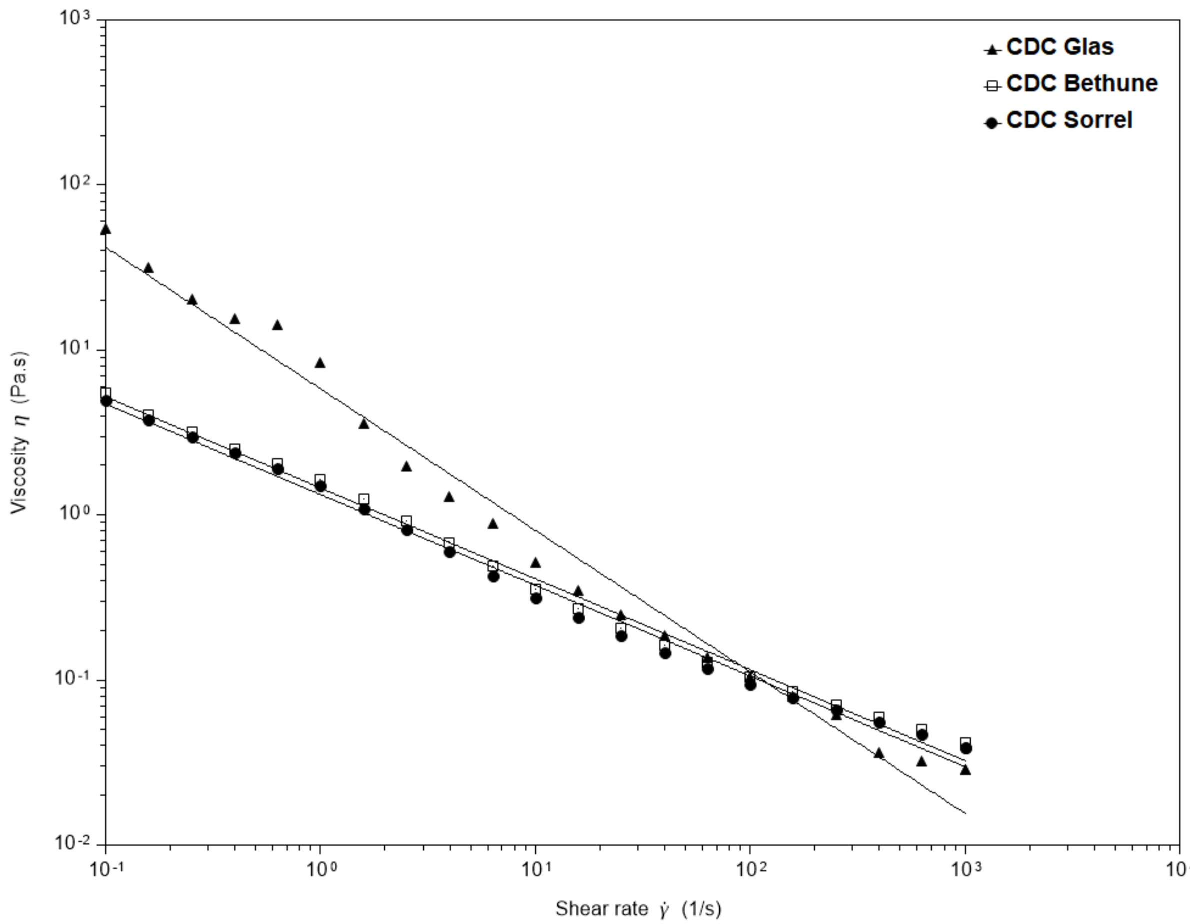


Figure 4.2 Effect of flaxseed cultivar on the dynamic flow behaviour of 1.00% flaxseed gum (FG) beverage solution extracted at 60°C (All the lines are fitted by Power Law, and plotted in logarithm scale).

4.6.2. Extraction temperature effects

Extraction temperature effects on FG beverage viscosity are shown in Figure 4.3. For all FG beverages, the apparent viscosity decreased as the shear rate increased. As shown in Table 4.4, the *n* and *k* coefficients of FG extracted at 60°C were similar to FG derived from 80°C, especially for CDC Bethune and CDC Sorrel. When increasing the extraction temperature from 60 to 80°C, the *k* coefficient slightly decreased, indicating a decrease in the pseudoplastic flow of these FG beverages.

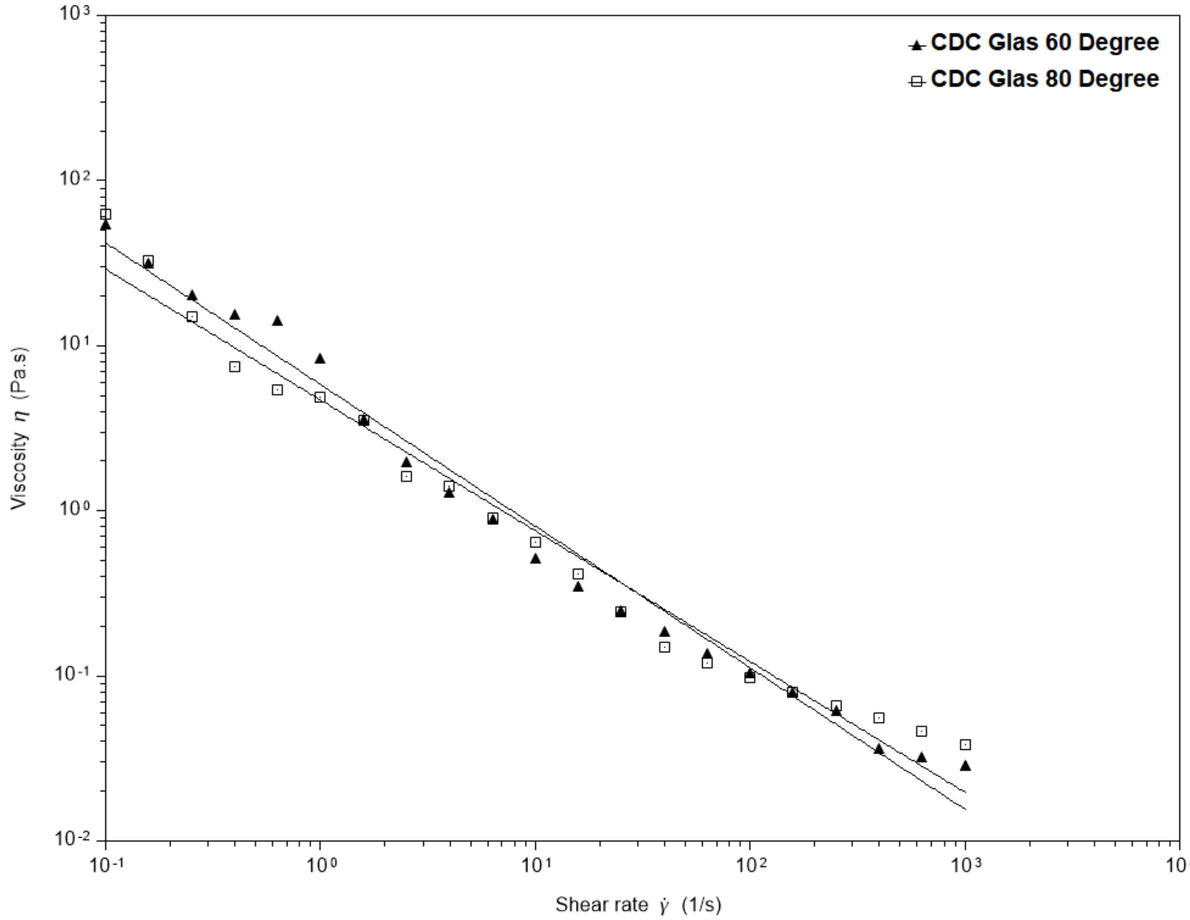


Figure 4.3 Effect of extraction temperature on the dynamic flow behaviour of 1.00% CDC Glas flaxseed gum (FG) beverage solution (All the lines are fitted by Power Law, and plotted in logarithm scale).

4.6.3. FG concentration effects

Shear thinning behaviour was exhibited for all FG beverages with concentration at 0.50% and 1.00% (w/v) FG, regardless of flaxseed cultivar or extraction temperature (Fig. 4.4). This behaviour indicated that apparent viscosity dropped with increased shear rate.

The other trend, as identified in Table 4.4, was that with increasing FG concentration, coefficient k increased significantly. As shown in Figure 4.5, 1.00% (w/v) CDC Glas FG beverage exhibited a higher viscosity than 0.50% (w/v) CDC Glas FG beverage. The high viscosity of FG solution and shear-thinning flow behavior is mainly due to high molecular weight of the neutral polysaccharides (Goh et al. 2006), thus, with increasing FG concentration, more neutral sugar would exist in the FG beverage, which would further increase the viscosity.

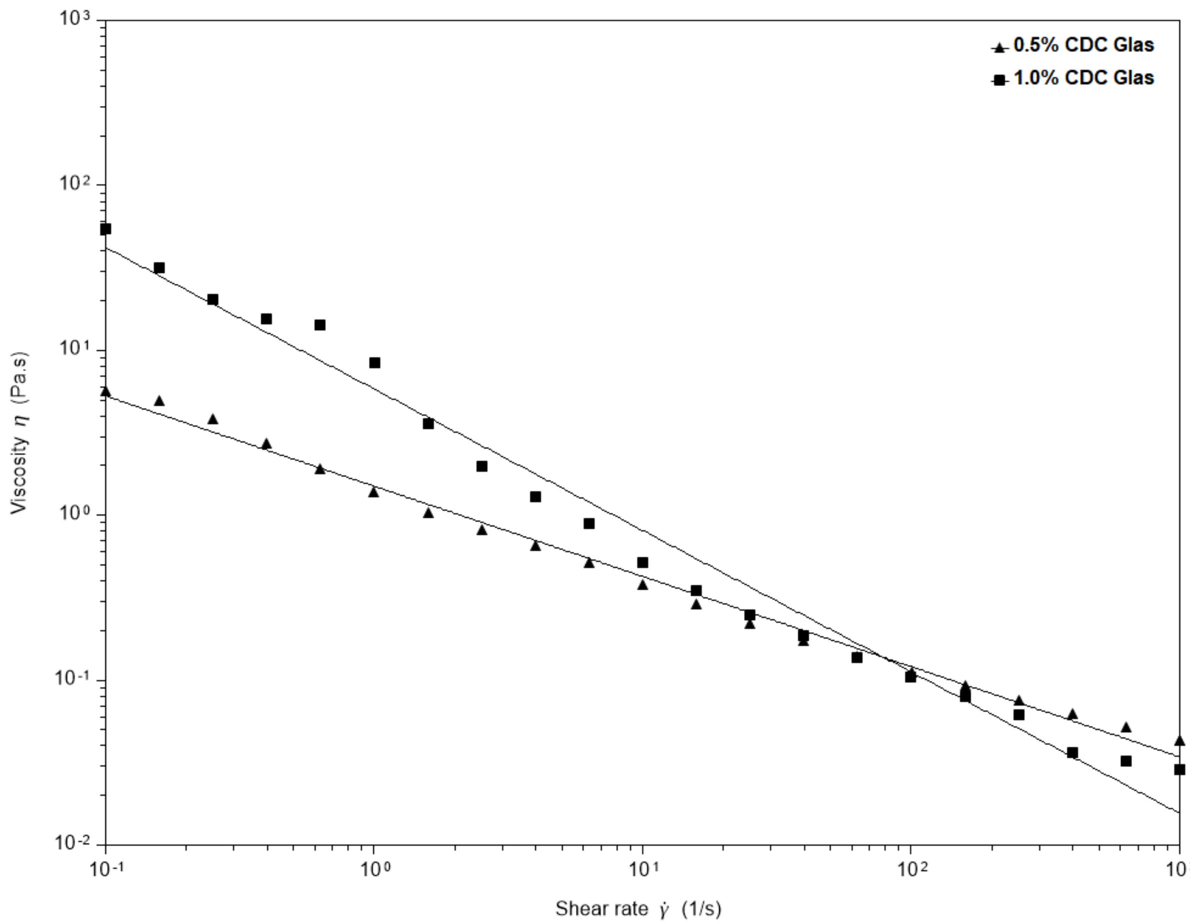


Figure 4.4 Effect of flaxseed gum (FG) beverage concentration on the dynamic flow behaviour of CDC Glas FG beverage extracted at 60°C (All the lines are fitted by Power Law, and plotted in logarithm scale).

4.7. Sensory Analysis

4.7.1. Sensory Attributes of FG Beverages

Sensory evaluation is a scientific method to measure, analyze, and interpret responses to food products as perceived by the human senses of sight, smell, touch, taste, and hearing (Kaur et al.

2018). It is widely applied to explore specific characteristics of a designed ingredient or food product by comparing similarities and differences (Kaur et al. 2018). For the sensory analysis of FG beverages, several different quality attributes play an important role. The present study was conducted to evaluate the sensory aspects and overall product acceptance of FG beverages, with the characteristics and definitions shown in Table 4.5. Among all the sensory parameters, the colour and product acceptability were judged based on the degree of preference, while odour, texture, flavour, and after-taste were evaluated based on the specific intensities. Table 4.6 presents the 8-point hedonic scale score sheet used in this study.

Table 4.5 Definitions of attributes for flaxseed gum (FG) beverage testing.

SENSORY ATTRIBUTES	**DEFINITIONS**
COLOUR DESIRABILITY	The degree of colour preference of the product
ODOUR/SMELL	The intensity of odour of the product
TEXTURE/MOUTHFEEL	The degree of flow characteristics of liquid product in the mouth
FLAVOUR INTENSITY (SALTY, SWEETNESS, AND SOUR INTENSITY)	The amount of salty, sweetness, and sour flavour present in the mouth after complete mastication
AFTER-TASTE INTENSITY	The amount of off-flavour present in the mouth after complete mastication (please describe, if any off-flavour present)
PRODUCT ACCEPTABILITY	The degree of acceptability of the product

4.7.2. Sensory Profiles of FG Beverages

To study the sensory characteristics of FG beverages, 0.50% and 1.00% (w/v) FG beverages were tested by a team of selected and semi-trained panelists. Figure 4.5 and 4.6 present the average sensory profiles of samples with different flaxseed cultivars, extraction temperatures, and FG concentrations in terms of colour, odour, texture, taste intensity, and after-taste intensity.

4.7.2.1. Colour Desirability

Appearance is the first factor the consumer uses to determine a food's quality and this includes colour, shape, texture, and other surface characteristics (Gat and Ananthanarayan 2016). Colour plays an essential role in consumer choice, since it will affect taste thresholds, sweetness, perception, food preference, pleasantness, and acceptability (Kaur et al. 2018). Frequently, products with transparency appearance would have better visual appeal, particularly for products like drinking beverages.

In this study, FG beverage generally had desirable transmittance appearance, and some exhibited a pale, yellow colour. On the 8-point hedonic scale, colour was rated 5.6 and 4.8 for 0.50% and 1.00 % (w/v) FG beverage, respectively. The score range of appearance varied from 4.1 (CDC Sorrel, 0.50%, and extracted at 80°C) to 6.2 (CDC Glas, 0.50%, and extracted at 80°C) for all the formulations, which was between "Slightly Undesirable" and "Moderately Desirable". Participants rated colour as acceptable for most FG beverage. CDC Sorrel exhibited a comparatively lower value (4.7) on the colour sensory attribute, while CDC Glas and CDC Bethune were rated at 5.7 and 5.1, separately. Extraction temperature also influenced the panelist's decisions; thus, panelists exhibited more colour desirability for FG extracted from 60°C (5.4) compared to FG extracted at 80°C (4.9). It is encouraging to compare this result with that found by Pimentel et al. (2015) who investigated apple juice supplemented with *Lactobacilus paracasei* ssp. that in their study, the judges indicated that they moderately liked the colour of clarified apple juices (hedonic values near 7 in a 9-point scale). Compared to their results, the appearance of FG beverage may need to be improved in the future.

4.7.2.2. Odour/smell

The sense of smell is one of the major contributors to the sensory system involved in the perception of food aromas and volatile flavours. These olfactory sensations can profoundly impact consumer perception of quality and acceptability of foods (Lawless 1991). In this study, FG beverage had a moderately bland odour with a faint smell of seeds as described by panelists. Overall, the scores of odour intensity for all the formulations were in the range of 5.4 (CDC Glas, 1.00%, w/v, and extracted at 80°C) to 6.6 (CDC Glas, 0.50%, w/v, and extracted at 60°C); thus the odour of FG beverage is “Slightly Bland” and “Very Bland” to the panelists. The average odour intensity rated by panelists is 6.0 for both 0.50% and 1.00% FG beverage, which falls into the category of “Very Bland”. According to all the panelists, CDC Sorrel (6.2) had a moderately bland smell, followed by CDC Glas (5.9) and CDC Bethune (5.6) showed a slightly bland smell. Furthermore, FG extracted at 60°C (6.1) had a more bland smell compared to FG beverage with FG extracted at 80°C (5.8).

4.7.2.3. Texture/mouth feel

Texture also impacts consumer acceptance of food products. For solid materials and products, mastication consists of shearing and grinding the product with teeth. Foods are controlled and directed between the teeth by the tongue, cheeks, and lips. In terms of liquid and semi-solid products, the tongue plays a more meaningful role than the teeth, since fewer efforts are required for disintegration. The motions of the tongue assist to shear the food and dilute it with saliva until the viscosity of food material is low enough for swallowing. During eating, the tongue moves about 30 times every minute (Szczesniak and Farkas 1962). The textural parameter is usually conducted for semi-solid food material, to specify how thick the material is, how long it coats the mouth, extent of difficulties to swallow, and to what extent it can retain its shape (Khan et al. 2015; Szczesniak and Farkas 1962).

In this study, panelists stated the beverage was only a bit thicker than water in the mouth. As shown in the Figure 4.5 and 4.6, the least slippery sample at a score of 4.8 was found to be 0.50% (w/v) CDC Sorrel extracted at 80°C, while the most slippery formulation at a score of 6.4 was FG beverage with CDC Glas extracted at 60°C with 0.50% concentration (w/v). The texture of the product was also perceived as 5.8 points for 0.50% (w/v) and 5.5 points for 1.00% (w/v) FG beverage, which both fall between “Slightly Slippery” to “Moderately Slippery”. By comparing the mouthfeel between various flaxseed cultivars, CDC Glas exhibited “Moderately Slippery” texture, while FG beverage made with CDC Bethune and CDC Sorrel seemed to produce a stickier mouthfeel to the panelists, and were rated at 5.7 and 5.2, respectively. Another finding is that the samples with FG extracted at 60°C (5.8) exhibited a more slippery texture compared to FG beverage with FG extracted at 80°C (5.5).

4.7.2.4. Flavour intensity (salty, sweetness, and sour intensity)

Flavour is considered as the most critical factor which determines product consumption, the period time of products stay in the market, and consumers’ repeat purchasing (Cardello, Schutz, and Lesher 2007). Therefore, the taste intensity and after-taste intensity are essential to maintain at a suitable level. In this study, FG beverage tasted a little sweet and pleasant with a minor off flavour presented in the mouth after complete mastication. The scores of flavour intensity for all FG beverages were between 3.5 (CDC Glas, 0.50%, w/v, extracted at 60°C) to 5.1 (CDC Glas, 0.50%, w/v, extracted at 80°C). The participants suggested an average score of 4.3 for taste intensity of both 0.50% and 1.00% (w/v) FG beverage, which was between “Slightly Intense” and “Slightly Bland”. Beverage made with CDC Bethune exhibited higher taste intensity (4.1) than the product prepared with CDC Glas (4.3) and CDC Sorrel (4.5).

4.7.2.5. After-taste intensity

After-taste intensity varied with formulation, and ranged from 4.3 (CDC Bethune, 0.50% and 1.00%, w/v, extracted at 60°C) to 5.5 (CDC Glas and CDC Sorrel, 0.50%, w/v, extracted at 80°C). The average was rated at 5.1 and 5.0 for 0.50% and 1.00% (w/v) FG beverage, respectively, which stayed in the categories of “Slightly Bland” and “Moderately Bland”. The after-taste intensity of CDC Bethune (4.8) was scored at “Slightly Intense”, which was stronger than CDC Glas (5.0) and CDC Sorrel (5.3). From Figure 4.5 and 4.6, no taste and after-taste intensity differences were detected with various extraction temperatures. Both FG extracted from 60°C and 80°C were rated at 4.3 for taste intensity, and 5.1 for after-taste intensity.

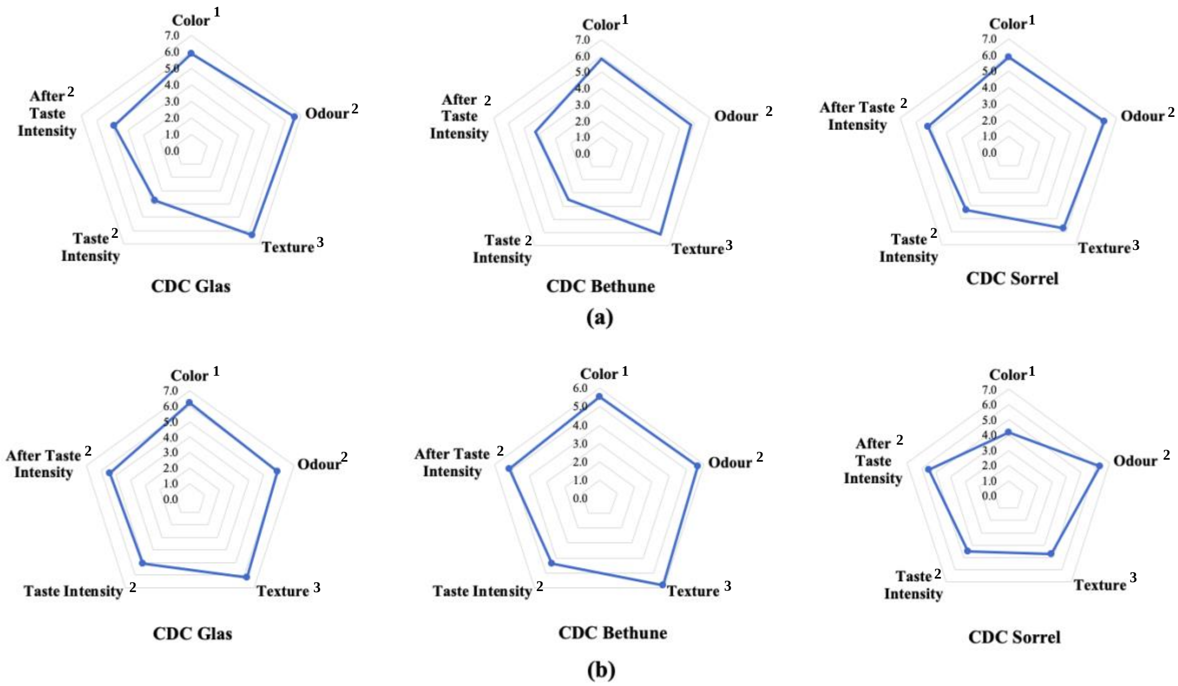


Figure 4.5 Radar plots of the sensory attributes of 0.50% flaxseed gum (FG) beverage with various flaxseed cultivars and gum extraction temperatures: (a) 60°C, and (b) 80°C.

[1] 8 = Extremely Desirable; 7 = Very Desirable; 6 = Moderately Desirable; 5 = Slightly Desirable; 4 = Slightly Undesirable; 3 = Moderately Undesirable; 2 = Very Undesirable; 1 = Extremely Undesirable.

[2] 8 = Extremely Bland; 7 = Very Bland; 6 = Moderately Bland; 5 = Slightly Bland; 4 = Slightly Intense; 3 = Moderately Intense; 2 = Very Intense; 1 = Extremely Intense.

[3] 8 = Extremely Slippery; 7 = Very Slippery; 6 = Moderately Slippery; 5 = Slightly Slippery; 4 = Slightly Sticky; 3 = Moderately Sticky; 2 = Very Sticky; 1 = Extremely Sticky.

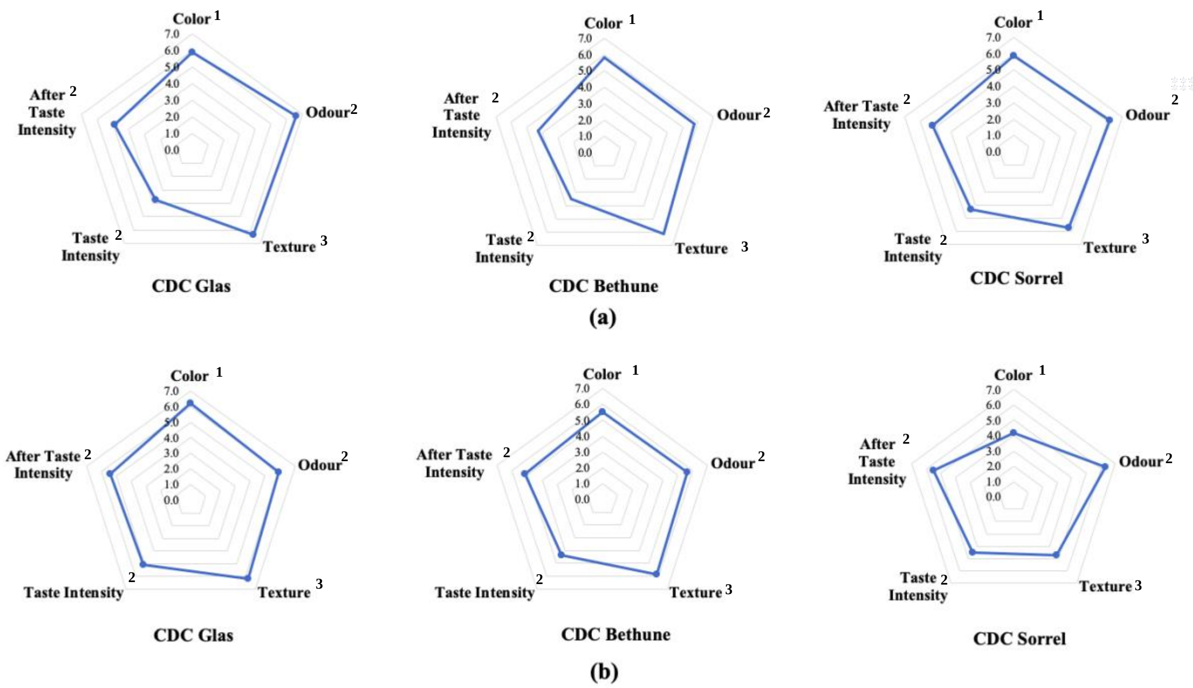


Figure 4.6 Radar plots of the sensory attributes of 1.00% FG beverage with various flaxseed cultivars and gum extraction temperatures: (a) 60°C, and (b) 80°C.

[1] 8 = Extremely Desirable; 7 = Very Desirable; 6 = Moderately Desirable; 5 = Slightly Desirable; 4 = Slightly Undesirable; 3 = Moderately Undesirable; 2 = Very Undesirable; 1 = Extremely Undesirable.

[2] 8 = Extremely Bland; 7 = Very Bland; 6 = Moderately Bland; 5 = Slightly Bland; 4 = Slightly Intense; 3 = Moderately Intense; 2 = Very Intense; 1 = Extremely Intense.

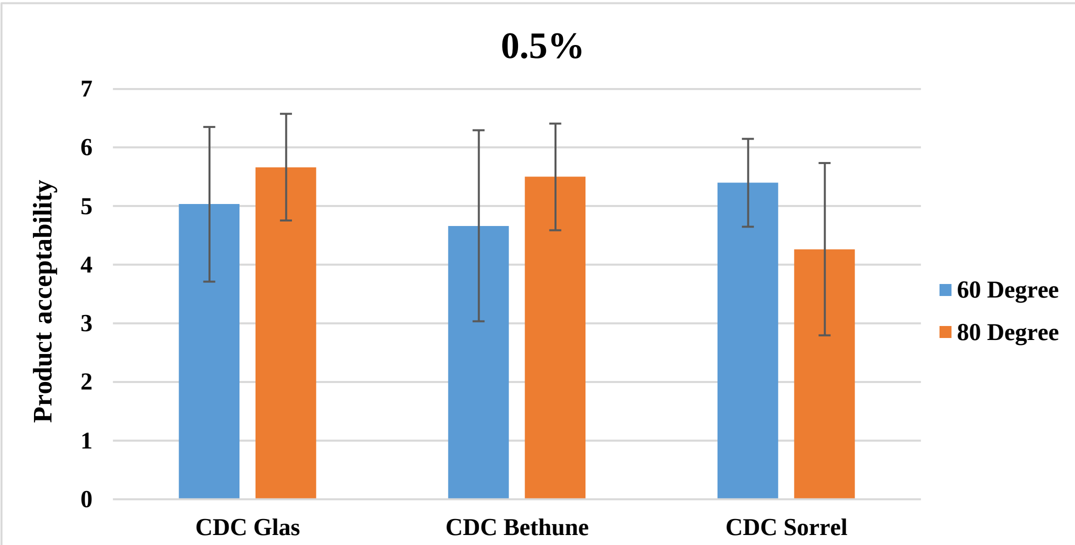
[3] 8 = Extremely Slippery; 7 = Very Slippery; 6 = Moderately Slippery; 5 = Slightly Slippery; 4 = Slightly Sticky; 3 = Moderately Sticky; 2 = Very Sticky; 1 = Extremely Sticky.

4.7.3. Product Acceptability of FG Beverage

According to the assessment about colour desirability, odour, texture, flavour intensity, after-taste intensity of FG beverage, the overall product acceptability, as the second stage of the sensory study, was conducted. For all FG beverages, the overall product acceptability was within the range of 4.3 (CDC Sorrel, 0.50%, w/v, extracted at 80°C) and 5.7 (CDC Glas, 0.50%, w/v, extracted at 80°C) (Fig. 4.7). The average product acceptability for 0.50% (w/v) FG beverage was 5.1 (Fig. 4.7 (a)), and 5.0 (w/v) for 1.00% (Fig. 4.7 (b)), which falls into the grade of "Slightly Acceptable" and "Moderately Acceptable". The most popular FG beverage formulation at both 0.50% and 1.00% (w/v) concentration was made with FG extracted from CDC Glas and extracted at 80°C. FG beverage at 0.50 % (w/v) extracted at 80°C from CDC Glas performed the best for overall product acceptability at 5.7, while 1.00% (w/v) FG beverage from CDC Glas with same extraction condition showed 5.5 customer acceptability.

The least popular formulation with 0.50% (w/v) concentration was the FG beverage made with CDC Sorrel FG extracted at 80°C, which had the score of 4.3, and fell into the scales between "Slightly Unacceptable" and "Slightly Acceptable". For the 1.00% (w/v) FG beverages, the formulation with FG from CDC Bethune extracted at 60°C was the least popular (4.7). Taken together, the results suggested that among all three flaxseed cultivars, FG extracted from CDC Glas exhibited better overall acceptability than CDC Bethune and CDC Sorrel (Figure 4.7 (a) and (b)). FG beverage made with CDC Glas had average product acceptability at 5.3, which is between "Slightly Acceptable" and "Moderately Acceptable", compared to score of 5.0 and 4.9 for CDC Bethune and CDC Sorrel, respectively. A comparison of the popularity of two extraction temperatures revealed that FG extracted at 80°C was more acceptable (5.1) than FG extracted at 60°C (5.0).

(a)



(b)

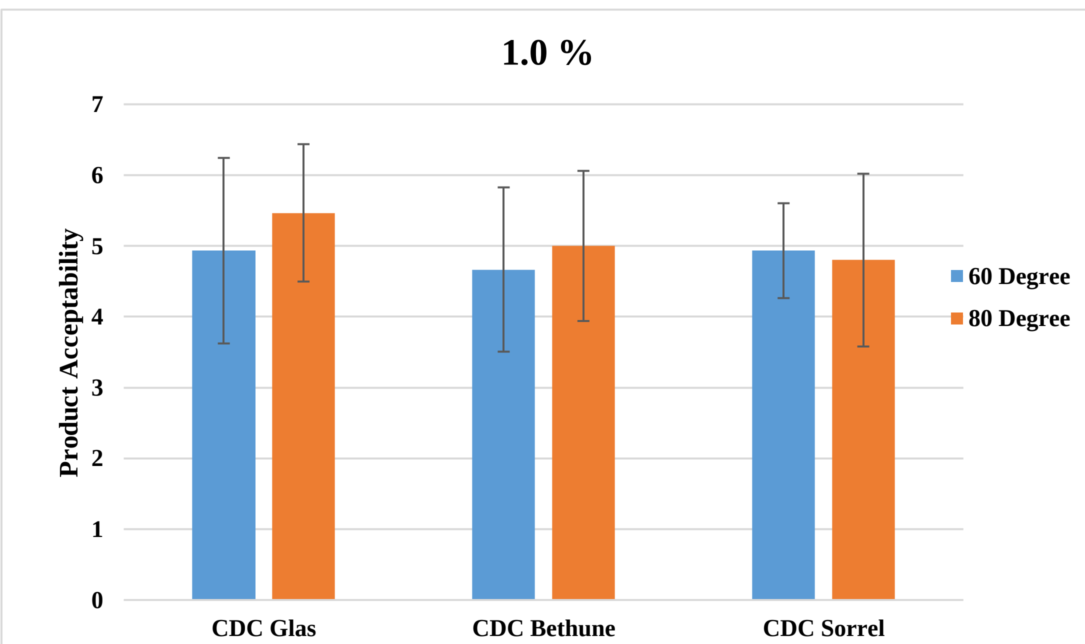


Figure 4.7 Mean overall product acceptability value on a 8-points hedonic scale from all panelists of flaxseed gum (FG) beverages for three flaxseed cultivars and two extraction temperatures at two FG concentrations: (a) 0.50% , and (b) 1.00%.

8 = Extremely Acceptable; 7 = Very Acceptable; 6 = Moderately Acceptable; 5 = Slightly Acceptable; 4 = Slightly Unacceptable; 3 = Moderately Unacceptable; 2 = Very Unacceptable; 1 = Extremely Unacceptable.

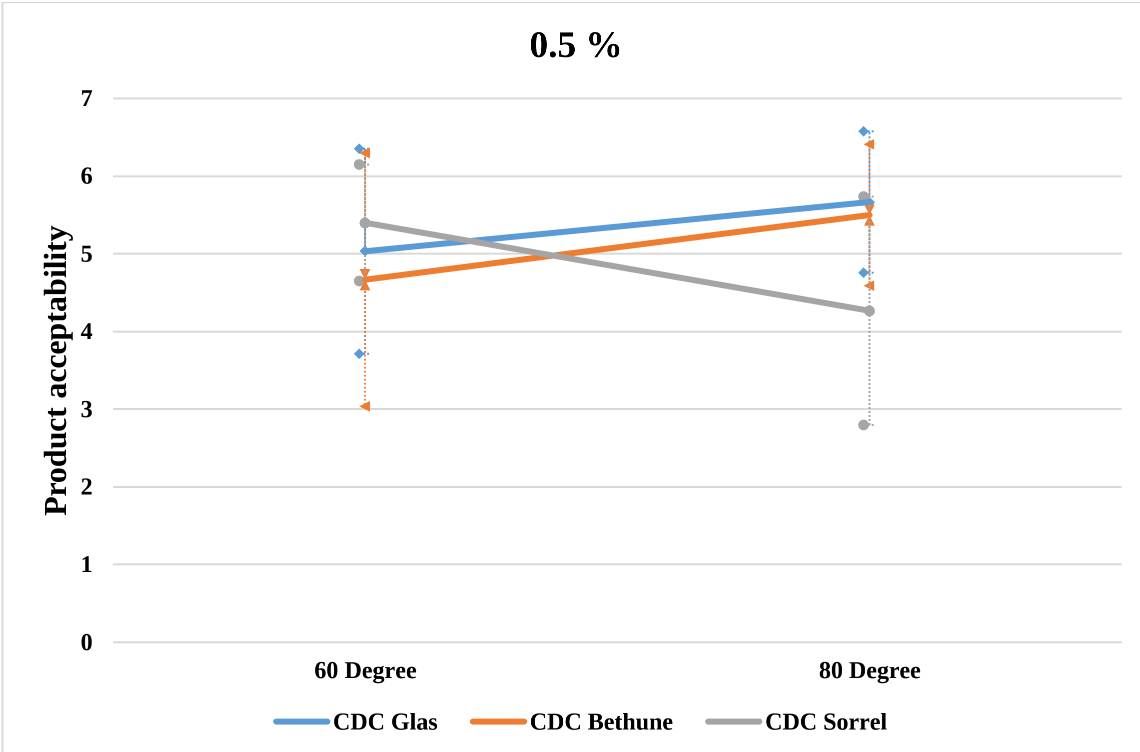
In order to identify whether flaxseed cultivars, extraction temperature, and/or FG concentration would influence the overall acceptability, further statistical tests were conducted (Table 4.6). From Table 4.6, it could be observed that three independent factors, flaxseed cultivar, extraction temperature, and concentration, did not bring any significant impact to the overall acceptability of FG beverage ($p > 0.05$); the interreacting factors, Cultivar * Concentration, Temperature * Concentration, and Cultivar * Temperature * Concentration, did not demonstrate any significant effects ($p > 0.05$) with regards to the overall FG beverage acceptability. However, it is interesting to note that the interreacting factor, cultivar and extraction temperature, would significantly contribute to the overall acceptability ($p < 0.05$). This may suggest that during the beverage production process, picking the best combination of cultivar and extraction temperature would give the FG beverage better product acceptability.

Table 4.6 Statistical analysis of cultivar, temperature, and concentration effects on overall product acceptability of flaxseed gum (FG) beverage.

Source	Type III Sum of Squares	df	Mean Square	F Value	Sig.
Intercept	**9100.278**	**1**	**9100.278**	**2306.030**	**0.000**
Cultivar	**11.706**	**2**	**5.853**	**1.483**	**0.232**
Temperature	**2.844**	**1**	**2.844**	**0.721**	**0.398**
Concentration	**1.344**	**1**	**1.344**	**0.341**	**0.561**
Cultivar * Temperature	**29.606**	**2**	**14.803**	**3.751**	**0.027**
Cultivar * Concentration	**1.239**	**2**	**0.619**	**0.157**	**0.855**
Temperature * Concentration	**0.400**	**1**	**0.400**	**0.101**	**0.751**
Cultivar * Temperature * Concentration	**9.050**	**2**	**4.525**	**1.147**	**0.322**
Error	**426.2**	**108**	**3.946**		

To further investigate the relationship between the overall acceptability and interreacting factor, cultivar * extraction temperature, the profiles were plotted. Figure 4.8 (a) is the profile of product acceptability against FG extraction temperature (60°C and 80°C) among three various flaxseed cultivars under a FG concentration of 0.50% (w/v). For CDC Glas and CDC Bethune, the overall acceptability increased with increasing extraction temperature from 60 to 80°C. Regarding CDC Sorrel, the mean value of product acceptability was reduced from 5.2 to 4.6 as the extraction temperature went up from 60 to 80°C. These results suggest that various flaxseed cultivars may need to have different extraction temperatures applied in order to result in better product acceptability. CDC Glas and CDC Bethune may exhibit better product acceptability using an 80°C extraction temperature, whereas CDC Sorrel would produce better product acceptability with a 60°C extraction temperature. Figure 4.8 (b) shows the profile of product acceptability against FG extraction temperature (60°C and 80°C) among three flaxseed cultivars under FG concentration of 1.00% (w/v). Similar trends could be found here as the customer acceptability increased as the extraction temperature went up for the flaxseed cultivars of CDC Glas and CDC Bethune, whereas FG beverage made with CDC Sorrel demonstrates improved scores when the FG is extracted at a lower extraction temperature.

(a)



(b)

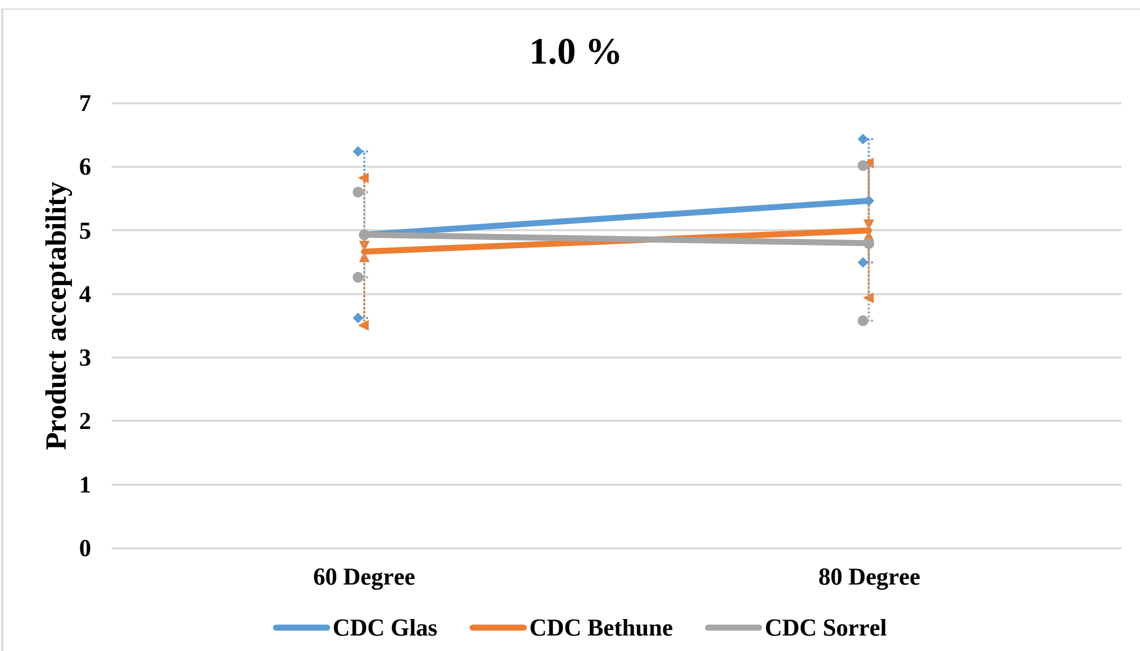


Figure 4.8 Product acceptability of different flaxseed gum (FG) beverage formulations with FG extracted at two temperatures (60°C and 80°C) among three various flaxseed cultivars under the FG concentrations: (a) 0.50%, and (b) 1.00%.

8 = Extremely Acceptable; 7 = Very Acceptable; 6 = Moderately Acceptable; 5 = Slightly Acceptable; 4 = Slightly Unacceptable; 3 = Moderately Unacceptable; 2 = Very Unacceptable; 1 = Extremely Unacceptable.

4.7.4. Effect of Flavour Compound Addition

Taken together, the results from sensory evaluations suggested that a FG beverage made with FG extracted from CDC Glas at 80°C with concentration at 1.00% could be considered as the most popular formulation. This formulation exhibited a desirable appearance, the least taste and after-taste intensities among all FG beverage designed, and it also had good odour and texture attributes. Given the assumption that an oral rehydration solution with orange flavour has superior overall acceptability to non-flavoured ones, the next stage of the study was to add flavour compound to optimize the FG beverage. In addition, a conventional oral rehydration solution product (non-flavored) in the market was included to compare the sensory attributes with the designed FG beverage (with/without orange flavour).

As shown in Figure 4.9, the scores of all sensory attributes varied between the three products. First, for colour desirability the conventional product is a transparent product, while the orange flavour FG beverage presented with a pale orange or yellowish colour. In Figure 4.9, these three products did not show significant differences in their color desirability. Second, significant differences in odour intensity were found between these three tested beverages. The conventional product had been rated at “Very Bland” to “Extremely bland” odour intensity level. At the same time, the orange flavour FG beverage exhibited higher odour intensity, which fell to “Slightly Intense”, while the 1.00% (w/v) CDC Glas FG beverage was in between. Third, for texture attributes, the conventional product made without FG, the mouthfeel was rated as 7.1 for the panelists, which fell into the scale between “Very Slippery” and “Extremely Slippery”. Compared to that, the two products with FG exhibited decreased scores in the texture attributes, which had scores at 5.6 and 6.2 without or with orange flavour FG beverage, respectively, but further analysis showed that none of these differences were statically significant. Fourth, FG beverage made with FG extracted from CDC Glas at 80°C (1.00%, w/v) exhibited the highest score in taste intensity. The orange flavour FG beverage showed the same taste intensity level as the conventional product. Further, statistical tests revealed that there was a significant difference between CDC Glas FG beverage with the conventional product and orange flavour FG beverage, which suggested that the orange flavour compound might help to improve the taste/flavour to the consumers. Fifth, the after-taste intensity of these three tested beverages were close to each other. No significant difference between these three groups was evident. The orange flavour one showed the lowest off flavour intensity, followed by 1.00% (w/v) CDC Glas FG beverage, and the conventional product exhibited the highest after-taste intensity. Lastly, the product acceptability of these three beverages were similar to each other, and they all fell into the scale between "Slightly Acceptable" and "Moderately Acceptable". Further statistical tests showed that there were no significant differences were observed.

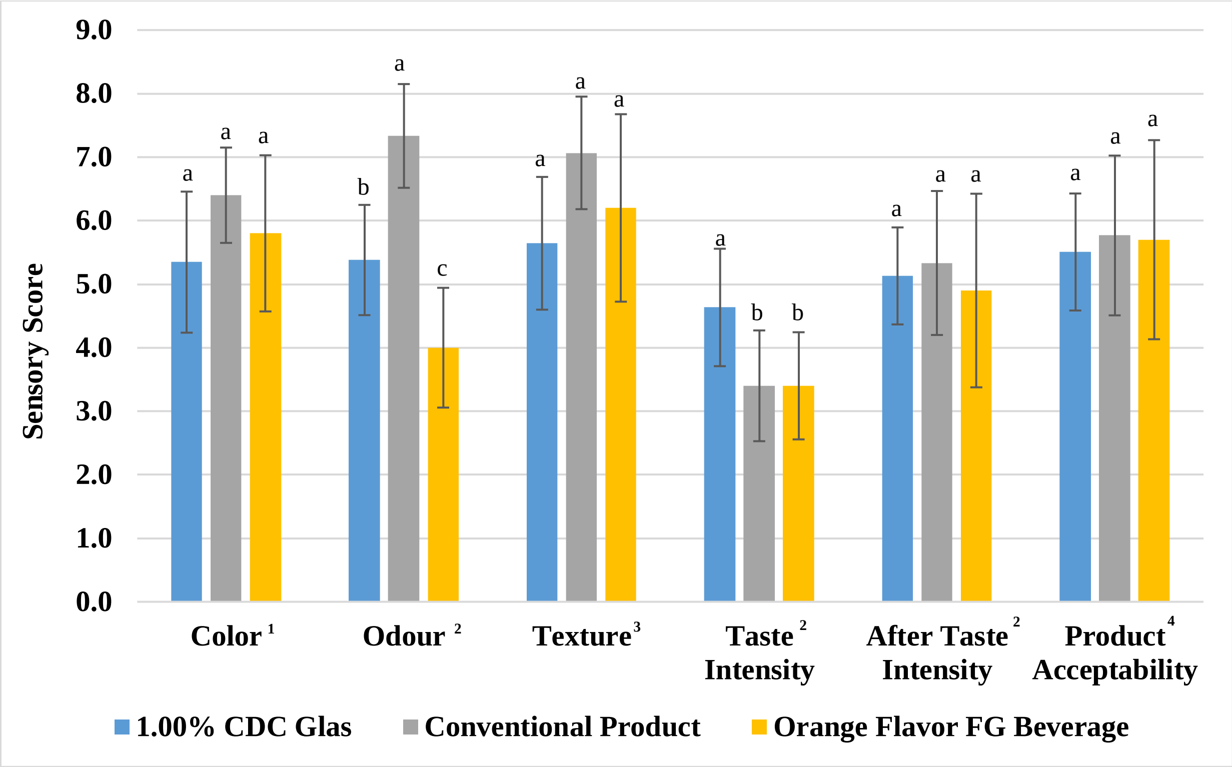


Figure 4.9 The mean value of sensory attributes of designed flaxseed gum (FG) beverage, conventional product, and orange flavoured beverage. Different superscripts (a, b, c) in the same sensory attribute category indicate statistically significant differences ($p < 0.05$).

[1] 8 = Extremely Desirable; 7 = Very Desirable; 6 = Moderately Desirable; 5 = Slightly Desirable; 4 = Slightly Undesirable; 3 = Moderately Undesirable; 2 = Very Undesirable; 1 = Extremely Undesirable.

[2] 8 = Extremely Bland; 7 = Very Bland; 6 = Moderately Bland; 5 = Slightly Bland; 4 = Slightly Intense; 3 = Moderately Intense; 2 = Very Intense; 1 = Extremely Intense.

[3] 8 = Extremely Slippery; 7 = Very Slippery; 6 = Moderately Slippery; 5 = Slightly Slippery; 4 = Slightly Sticky; 3 = Moderately Sticky; 2 = Very Sticky; 1 = Extremely Sticky.

[4] 8 = Extremely Acceptable; 7 = Very Acceptable; 6 = Moderately Acceptable; 5 = Slightly Acceptable; 4 = Slightly Unacceptable; 3 = Moderately Unacceptable; 2 = Very Unacceptable; 1 = Extremely Unacceptable.

5. SUMMARY AND CONCLUSIONS

This study was designed to formulate a novel FG beverage based on the current conventional oral rehydration products in the market, which would give satisfactory physicochemical properties and sensory characteristics. According to all the properties tested, flaxseed cultivars, gum extraction temperature, and flaxseed gum concentration all have effects on the physicochemical properties of final oral rehydration beverage product. Formulations of FG beverage made with FG extracted at 60°C with CDC Bethune and extracted at 80°C with CDC Glas might be the better choices for improved appearance and mouthfeel. The sensory study suggested that FG beverage made with FG extracted from CDC Glas at 80°C with concentration at 1.00% could be considered as the most popular formulation, as it exhibited desirable appearance, least taste and after-taste intensities among all FG beverages tested, and it also had more desirable odour and texture attributes. Studies on the effect of flavour compound addition showed that the additional of orange flavour compound, it would lower the flavour intensity of FG beverage significantly.

The study has potential limitations. First, the method used for the detection of neutral sugar is limited, and can be improved using high performance liquid chromatography (HPLE) methods. Second, the sensory profiles and overall product acceptability of FG beverage was based on the sensory study of 12 semi-trained panelists, and we only evaluated adult assessment and preference on the oral rehydration solution. However, the assessment and preference may have potential differences between adults and children. Our estimates may be conservative or overestimate the likeness of the FG beverage. Future studies can be designed to conduct sensory evaluations in children.

In conclusion, FG beverage exhibited desirable characteristics and sensory evaluation results suggesting that FG beverage made with FG extracted from CDC Glas at 80°C with concentration at 1.00% (w/v) is the most accepted beverage to give satisfactory product acceptability.

6. FUTURE DIRECTIONS

Flax has been used by human society for centuries due to its various applications. However, flax products have received recent attention as a source of new raw materials for a variety of health benefits. Consumers are increasingly interested in healthy foods and functional products because of the growing awareness of the link between diet and health. Results from this study illustrated the possibility of developing an oral rehydration solution with FG as a functional beverage. Further analysis is necessary to increase appearance and palatability of the product. Acids such malic acid could be added to enhance the intrinsic flavour (Reddy et al. 2016), as well as give freshness to the beverage (Jolicoeur 2011). Sugar and colour compound addition can also enhance appearance and palatability. Other major areas of investigation include product consistency, shelf stability, and antiviral properties of this FG addition to oral rehydration solutions. The product consistency evaluation can be achieved through setting standards for each testing parameter, such as yield and appearance, by mixing various flaxseed cultivars with different ratios and subsequent determination of the optimal ratio for flaxseeds cultivars mixing. The shelf-life can be tested through microbiological evaluation. Mesophilic aerobes, total and thermotolerant coliforms, *Salonella* sp., yeasts, and molds should be assessed during the 28 days of refrigerated storage. The antiviral test can be conducted on gut virus testing. Anti-HBV activities, anti-hepatitis B surface antigen (HBsAg) and anti-hepatitis B envelope antigen (HbeAg) could be measured by commercially available kit. The immunomodulatory activity can be investigated using the murine macrophage cell with RAW 264.7 cell model, and its antiproliferative activity against HBV virus can be evaluated using HepG 2.2.15 cell model systems using the colourimetric MTT assay.

REFERENCES

Adinsi, Laurent, Noël H. Akissoé, Générose Dalodé-Vieira, Victor B. Anihouvi, Genevieve Fliedel, Christian Mestres, and Joseph D. Hounhouigan. 2015. "Sensory Evaluation and Consumer Acceptability of a Beverage Made from Malted and Fermented Cereal: Case of Gowe from Benin." *Food Science & Nutrition* 3 (1): 1–9.

Adlercreutz, Herman. 2007. "Lignans and Human Health." *Critical Reviews in Clinical Laboratory Sciences* 44 (5–6): 483–525.

Aliani, Michel, Donna Ryland, and Grant N. Pierce. 2012. "Effect of Flax Addition on the Flavour Profile and Acceptability of Bagels." *Journal of Food Science* 77 (1): S62–70.

Aliev, R. K. 1946. "New Galenical Preparations from Flax Seeds." *American Journal of Pharmacy and the Sciences Supporting Public Health* 118 (12): 439.

Aspinall, G. O. 1983. "Classification of Polysaccharides." *The Polysaccharides* 2 1–9.

Berglund, D. R. 2002. "Flax: New Uses and Demands." In *Trends in New Crops and New Uses*, 358–360. Alexandria, VA: ASHS Press.

Bhatty, R. S. 1993. "Further Compositional Analyses of Flax: Mucilage, Trypsin Inhibitors and Hydrocyanic Acid." *Journal of the American Oil Chemists' Society* 70 (9): 899–904.

Bhatty, R. S., and P. Cherdkiatgumchai. 1990. "Compositional Analysis of Laboratory-Prepared and Commercial Samples of Linseed Meal and of Hull Isolated from Flax." *Journal of the American Oil Chemists' Society* 67 (2): 79–84.

Biliaderis, Costas G., and Marta S. Izydorczyk. 2006. *Functional Food Carbohydrates*. CRC Press, Boca Raton, London, New York, 2007.

Blackburn, N. A., J. S. Redfern, H. Jarjis, A. M. Holgate, I. Hanning, J. H. Scarpello, I. T. Johnson, and N. W. Read. 1984. "The Mechanism of Action of Guar Gum in Improving Glucose Tolerance in Man." *Clinical Science* 66 (3): 329–336.

Booker, H. M., G. G. Rowland, and K. Y. Rashid. 2013. "CDC Glas Oilseed Flax." *Canadian Journal of Plant Science* 94 (2): 451–52.

Cardello, Armand V., Howard G. Schutz, and Larry L. Lesher. 2007. “Consumer Perceptions of Foods Processed by Innovative and Emerging Technologies: A Conjoint Analytic Study.” *Innovative Food Science & Emerging Technologies* 8 (1): 73–83.

Carraro, Júlia Cristina Cardoso, Maria Inês de Souza Dantas, Ana Cristina Rocha Espeschit, Hércia Stampini Duarte Martino, and Sônia Machado Rocha Ribeiro. 2012. “Flaxseed and Human Health: Reviewing Benefits and Adverse Effects.” *Food Reviews International* 28 (2): 203–30.

Carvalho, Thiago S., Adrian Lussi, Thomas Jaeggi, and Dein L. Gambon. 2014. “Erosive Tooth Wear in Children.” In *Erosive Tooth Wear*, 25:262–278.

“CDC Flax Breeding Program - CDC Flax - College of Agriculture and Bioresources - University of Saskatchewan.” n.d. Accessed May 3, 2019. https://agbio.usask.ca/cdcflax/.

Chen, H. H., Shi-Ying Xu, and Zhang Wang. 2007. “Interaction between Flaxseed Gum and Meat Protein.” *Journal of Food Engineering* 80 (4): 1051–1059.

Chen, Jianmin, Jasdeep K. Saggar, Wendy E. Ward, and Lilian U. Thompson. 2011. “Effects of Flaxseed Lignan and Oil on Bone Health of Breast-Tumor-Bearing Mice Treated with or without Tamoxifen.” J*ournal of Toxicology and Environmental Health*, Part A 74 (12): 757–768.

Chhinnan, M. S., K. H. McWatters, and V. N. M. Rao. 1985. “Rheological Characterization of Grain Legume Pastes and Effect of Hydration Time and Water Level on Apparent Viscosity.” *Journal of Food Science* 50 (4): 1167–71.

Chornick, Tricia Laini. 2002. “Effect of Cultivar and Sequential Ethanol Precipitation on the Physicochemical Properties of Flaxseed Mucilage.” http://mspace.lib.umanitoba.ca/handle/1993/19583.

Coşkuner, Yalçın, and Erşan Karababa. 2007. “Some Physical Properties of Flaxseed (Linum Usitatissimum L.).” *Journal of Food Engineering* 78 (3): 1067–1073.

Cui, S.W. 2005. *Food Carbohydrates: Chemistry, Physical Properties, and Applications.* Boca Raton, FL: Taylor and Francis.

Cui, W. 2000. *Polysaccharide Gums from Agricultural Products: Processing, Structures and Functionality*. Technomic Publishing Companry Inc, Lancaster, USA 2001.

Cui, W., E. Kenaschuk, and G. Mazza. 1996. “Influence of Genotype on Chemical Composition and Rheological Properties of Flaxseed Gums.” *Food Hydrocolloids* 10 (2): 221–227.

Cui, W., and G. Mazza. 1997. "Methods for Dehulling of Flaxseed, Producing Flaxseed Kernels and Extracting Lignans and Watersoluble Fibre from the Hulls." Int Patent CA2167951.

Cui, W., G. Mazza, and C. G. Biliaderis. 1994. "Chemical Structure, Molecular Size Distributions, and Rheological Properties of Flaxseed Gum." *Journal of Agricultural and Food Chemistry* 42 (9): 1891–1895.

Cui, W., G. Mazza, B. D. Oomah, and C. G. Biliaderis. 1994. "Optimization of an Aqueous Extraction Process for Flaxseed Gum by Response Surface Methodology." LWT-*Food Science and Technology* 27 (4): 363–369.

Cunnane, Stephen C., Sujata Ganguli, Chantale Menard, Andrea C. Liede, Mazen J. Hamadeh, Zhen-Yu Chen, Thomas MS Wolever, and David JA Jenkins. 1993. "High α-Linolenic Acid Flaxseed (Linum Usitatissimum): Some Nutritional Properties in Humans." *British Journal of Nutrition* 69 (2): 443–453.

Daun, J.K., Barthet, V., Chornick, T. L., and Duguid S. 2003. "Structure, composition, and variety development of flaxseed." Flaxseed in human nutrition. 6-45.

Dev, D. K., and E. Quensel. 1988. "Preparation and Functional Properties of Linseed Protein Products Containing Differing Levels of Mucilage." *Journal of Food Science* 53 (6): 1834–1837.

Diederichsen, Axel, J. Philip Raney, and Scott D. Duguid. 2006. "Variation of Mucilage in Flax Seed and Its Relationship with Other Seed Characters." *Crop Science* 46 (1): 365–371.

Dorrell, D. G. 1970. "Distribution of Fatty Acids within the Seed of Flax." *Canadian Journal of Plant Science* 50 (1): 71–75.

Edwards, C. A., N. A. Blackburn, L. Craigen, P. Davison, J. Tomlin, K. Sugden, I. T. Johnson, and N. W. Read. 1987. "Viscosity of Food Gums Determined in Vitro Related to Their Hypoglycemic Actions." *The American Journal of Clinical Nutrition* 46 (1): 72–77.

El-Beltagi, H. S., Z. A. Salama, and D. M. El-Hariri. 2007. "Evaluation of Fatty Acids Profile and the Content of Some Secondary Metabolites in Seeds of Different Flax Cultivars (Linum Usitatissimum L.)." *General and Applied Plant Physiology* 33 (3–4): 187–202.

Eyres, Laurence. 2015. "Flaxseed Fibre-a Functional Superfood?" *Food New Zealand* 15 (5): 24.

"FAOSTAT." n.d. Accessed March 25, 2019. http://www.fao.org/faostat/en/#data/QC.

Fedeniuk, Ricky W., and Costas G. Biliaderis. 1994. "Composition and Physicochemical Properties of Linseed (Linum Usitatissimum L.) Mucilage." *Journal of Agricultural and Food Chemistry* 42: 240–240.

Flax Council of Canada. "Chapter 11: Varieties." 2015. Flax Council of Canada (blog). Accessed February 26, 2019. https://flaxcouncil.ca/growing-flax/chapters/varieties/.

"Flax FAQs - CDC Flax - College of Agriculture and Bioresources - University of Saskatchewan." n.d. Accessed May 8, 2019. https://agbio.usask.ca/cdcflax/flax-faqs.php.

Franklin, B. 2009. Flaxseed Health Benefits and Side Effects. Accessed April 2, 2018. https://www.dietaryfiberfood.com/nutrition/flax-seed.php

Garcia-Ochoa, F, and J A Casas. 1992. "Viscosity of Locust Bean (Ceratonia Siliqua) Gum Solutions." *Journal of the Science of Food and Agriculture* 59 (1): 97–100.

Gat, Yogesh, and Laxmi Ananthanarayan. 2016. "Use of Paprika Oily Extract as Pre-Extrusion Colouring of Rice Extrudates: Impact of Processing and Storage on Colour Stability." *Journal of Food Science and Technology* 53 (6): 2887–2894.

Glicksman, Martin. 1963. "Utilization of Natural Polysaccharide Gums in the Food Industry." In *Advances in Food Research*, edited by C. O. Chichester, E. M. Mrak, and G. F. Stewart, 11:109–200. Academic Press.

Goh, Kelvin KT, D. Neil Pinder, Christopher E. Hall, and Yacine Hemar. 2006. "Rheological and Light Scattering Properties of Flaxseed Polysaccharide Aqueous Solutions." *Biomacromolecules* 7 (11): 3098–3103.

González, M. E., B. Alarcón, and L. Carrasco. 1987. "Polysaccharides as Antiviral Agents: Antiviral Activity of Carrageenan." *Antimicrobial Agents and Chemotherapy* 31 (9): 1388–93.

Goyal, Ankit, Vivek Sharma, Neelam Upadhyay, Sandeep Gill, and Manvesh Sihag. 2014. "Flax and Flaxseed Oil: An Ancient Medicine & Modern Functional Food." *Journal of Food Science and Technology* 51 (9): 1633–1653.

Haase, G. 2010. "Functional and Speciality Beverage Technology." *International Dairy Journal* 20 (1): 65–66.

Hadley, M., C. Lacher, and J. Mitchell-Fetch. 1992. "Fiber in Flaxseed." In *Proc. Flax Inst,* 54: 79–83.

Hall III, Clifford, Mehmet C. Tulbek, and Yingying Xu. 2006. "Flaxseed." *Advances in Food and Nutrition Research* 51: 1–97.

"Health Effects of Flaxseed Mucilage, Lignans." 1997. Flax Council of Canada (blog). January 1, 1997. Accessed March 26, 2019. https://flaxcouncil.ca/abstract/health-effects-of-flaxseed-mucilage-lignans/.

Imram, Nazlin. 1999. "The Role of Visual Cues in Consumer Perception and Acceptance of a Food Product." *Nutrition & Food Science* 99 (5): 224–228.

Izydorczyk, Marta, Steve W. Cui, and Qi Wang. 2005. "Food Carbohydrates: Chemistry, Physical Properties, and Applications." Eds. Cui SW and Wang Q, CRC Press, Boca Raton, 263–307.

Jain, R. K., and P. M. Ganorkar. 2014. "Effect of Flaxseed Incorporation on Physical, Sensorial, Textural and Chemical Attributes of Cookies." *International Food Research Journal* 21(4): 1515-1521.

Jani, Girish K., Dhiren P. Shah, Vipul D. Prajapati, and Vineet C. Jain. 2009. "Gums and Mucilages: Versatile Excipients for Pharmaceutical Formulations." *Asian J Pharm Sci* 4 (5): 309–323.

Jenkins, D. J. A. 1995. *Incorporation of Flaxseed or Flaxseed Components into Cereal Foods.* AOCS Press: Champaign, IL.

Jenkins, David JA, Cyril WC Kendall, Edward Vidgen, Sanjiv Agarwal, A. Venket Rao, Rachel S. Rosenberg, Eleftherios P. Diamandis, Renato Novokmet, Christine C. Mehling, and Tina Perera. 1999. "Health Aspects of Partially Defatted Flaxseed, Including Effects on Serum Lipids, Oxidative Measures, and Ex Vivo Androgen and Progestin Activity: A Controlled Crossover Trial." *The American Journal of Clinical Nutrition* 69 (3): 395–402.

Jolicoeur, Claude. 2011. "Acidity and pH of Apple Juice." *North American Fruit Explorers* 44: 7–11.

Kaewmanee, Thammarat, Lucia Bagnasco, Soottawat Benjakul, Silvia Lanteri, Carlo F. Morelli, Giovanna Speranza, and M. Elisabetta Cosulich. 2014. "Characterisation of Mucilages Extracted from Seven Italian Cultivars of Flax." *Food Chemistry* 148: 60–69.

Kajla, Priyanka, Alka Sharma, and Dev Raj Sood. 2015. "Flaxseed—a Potential Functional Food Source." *Journal of Food Science and Technology* 52 (4): 1857–71.

Katare, C., S. Saxena, S. Agrawal, GBKS Prasad, and P. S. Bisen. 2012. "Flax Seed: A Potential Medicinal Food." *J Nutr Food Sci* 2 (120): 2.

Kaur, Parvinder, Roji Waghmare, Vikas Kumar, Prasad Rasane, Sawinder Kaur, and Yogesh Gat. 2018. “Recent Advances in Utilization of Flaxseed as Potential Source for Value Addition.” *OCL*, 25, A304.

Kaushik, Pratibha, Kim Dowling, Raju Adhikari, Colin J. Barrow, and Benu Adhikari. 2017. “Effect of Extraction Temperature on Composition, Structure and Functional Properties of Flaxseed Gum.” *Food Chemistry 21*5 (January): 333–40.

Khalloufi, Seddik, Marcela Alexander, H. Douglas Goff, and Milena Corredig. 2008. “Physicochemical Properties of Whey Protein Isolate Stabilized Oil-in-Water Emulsions When Mixed with Flaxseed Gum at Neutral pH.” *Food Research International* 41 (10): 964–972.

Khalloufi, Seddik, Milena Corredig, H. Douglas Goff, and Marcela Alexander. 2009. “Flaxseed Gums and Their Adsorption on Whey Protein-Stabilized Oil-in-Water Emulsions.” *Food Hydrocolloids* 23 (3): 611–18.

Khan, Mohammad Imtiyaj, P. S. C. Sri Harsha, A. S. Chauhan, S. V. N. Vijayendra, M. R. Asha, and P. Giridhar. 2015. “Betalains Rich Rivina Humilis L. Berry Extract as Natural Colourant in Product (Fruit Spread and RTS Beverage) Development.” *Journal of Food Science and Technology* 52 (3): 1808–13.

Koocheki, Arash, Ali Reza Taherian, Seyed MA Razavi, and Aram Bostan. 2009. “Response Surface Methodology for Optimization of Extraction Yield, Viscosity, Hue and Emulsion Stability of Mucilage Extracted from Lepidium Perfoliatum Seeds.” *Food Hydrocolloids* 23 (8): 2369–2379.

Larsen, M. J., and B. Nyvad. 1999. “Enamel Erosion by Some Soft Drinks and Orange Juices Relative to Their pH, Buffering Effect and Contents of Calcium Phosphate.” *Caries Research* 33 (1): 81–87.

Lawless, Harry. 1991. “The Sense of Smell in Food Quality and Sensory Evaluation.” *Journal of Food Quality* 14 (1): 33–60.

Lesser, D. 1983. “Marketing and Sensory Quality.” In A. A. Williams, & R. K. Atkin (Eds.), *Sensory quality in foods and beverages: Definition, Measurement and Control,* 448–466. Chichester, England: Ellis Horwood Limited.

Lin, Hsiang-Yun, and Lih-Shiuh Lai. 2009. “Isolation and Viscometric Characterization of Hydrocolloids from Mulberry (Morus Alba L.) Leaves.” *Food Hydrocolloids* 23 (3): 840–48.

Liu, Hua, and NA Michael Eskin. 1998. “Interactions of Native and Acetylated Pea Starch with Yellow Mustard Mucilage, Locust Bean Gum and Gelatin.” *Food Hydrocolloids* 12 (1): 37–41.

Liu, Jun, Youn Young Shim, Jianheng Shen, Yong Wang, Supratim Ghosh, and Martin J. T. Reaney. 2016. “Variation of Composition and Functional Properties of Gum from Six Canadian Flaxseed (Linum Usitatissimum L.) Cultivars.” *International Journal of Food Science & Technology* 51 (10): 2313–2326.

Liu, Lina, Zhifei He, and Shamoli Mu. 2005. “The Characteristic and Appliance in Food Industry of Linseed Gum.” *Sichuan Food and Fermetation* 2005 (4).

Lussi, Adrian, and Thomas Jaeggi. 2006. “Dental Erosion in Children.” In *Dental Erosion*, 20:140–151.

Mazza, G., and C. G. Biliaderis. 1989. “Functional Properties of Flax Seed Mucilage.” *Journal of Food Science* 54 (5): 1302–1305.

Medina-Torres, L., E. Brito-De La Fuente, B. Torrestiana-Sanchez, and R. Katthain. 2000. “Rheological Properties of the Mucilage Gum (Opuntia Ficus Indica).” *Food Hydrocolloids* 14 (5): 417–424.

Mirhosseini, Hamed, and Bahareh Tabatabaee Amid. 2012. “A Review Study on Chemical Composition and Molecular Structure of Newly Plant Gum Exudates and Seed Gums.” *Food Research International* 46 (1): 387–398.

Monsigny, Michel, Claire Petit, and Annie-Claude Roche. 1988. “Colourimetric Determination of Neutral Sugars by a Resorcinol Sulfuric Acid Micromethod.” *Analytical Biochemistry* 175 (2): 525–30.

Morris, Diane H. 2007. Flax: A Health and Nutrition Primer. Winnipeg, Manitoba: Flax Council of Canada. https://flaxcouncil.ca/

Mridula, D., P. Barnwal and K. Singh. 2013. Dehulling characteristics of selected flaxseed varieties. *Food and Bioprocess Technology* 6:3284-3289.

Murakami, Christiana, Luciana Butini Oliveira, Aubrey Sheiham, Maria Salete Nahás Pires Corrêa, Ana Estela Haddad, and Marcelo Bönecker. 2011. “Risk Indicators for Erosive Tooth Wear in Brazilian Preschool Children.” *Caries Research* 45 (2): 121–129.

Muralikrishna, Gudipati, Paramahans V. Salimath, and Rudrapatnam N. Tharanathan. 1987. “Structural Features of an Arabinoxylan and a Rhamno-Galacturonan Derived from Linseed Mucilage.” *Carbohydrate Research* 161 (2): 265–271.

Oomah, B. D., and G. Mazza. 1993. “Flaxseed Proteins—a Review.” *Food Chemistry* 48 (2): 109–114.

Oomah, B. Dave. 2001. “Flaxseed as a Functional Food Source.” J*ournal of the Science of Food and Agriculture* 81 (9): 889–894.

Oomah, B. Dave, and G. Mazza. 2001. “Optimization of a Spray Drying Process for Flaxseed Gum.” *International Journal of Food Science & Technology* 36 (2): 135–143.

Paquin, P. 2009. Functional and Speciality Beverage Technology. Woodhead Publishing: Boca Raton, FL, USA, 2009.

Pavlov, A., F. Paynel, C. Rihouey, E. Porokhovinova, N. Brutch, and C. Morvan. 2014. “Variability of Seed Traits and Properties of Soluble Mucilages in Lines of the Flax Genetic Collection of Vavilov Institute.” *Plant Physiology and Biochemistry* 80: 348–361.

“Pedialyte - Uses, Side Effects, Interactions - MedBroadcast.com.” n.d. Accessed June 20, 2017. http://www.medbroadcast.com/drug/getdrug/pedialyte.

Pimentel, Tatiana Colombo, Grasiele Scaramal Madrona, Sandra Garcia, and Sandra Helena Prudencio. 2015. “Probiotic Viability, Physicochemical Characteristics and Acceptability during Refrigerated Storage of Clarified Apple Juice Supplemented with Lactobacillus Paracasei Ssp. Paracasei and Oligofructose in Different Package Type.” *LWT-Food Science and Technology* 63 (1): 415–422.

Prajapati, Vipul D., Girish K. Jani, Naresh G. Moradiya, and Narayan P. Randeria. 2013. “Pharmaceutical Applications of Various Natural Gums, Mucilages and Their Modified Forms.” *Carbohydrate Polymers* 92 (2): 1685–1699.

Qian, K. Y., S. W. Cui, Y. Wu, and H. D. Goff. 2012. “Flaxseed Gum from Flaxseed Hulls: Extraction, Fractionation, and Characterization.” *Food Hydrocolloids* 28 (2): 275–283.

Qin, Lan, Shi-ying Xu, and Wen-bin Zhang. 2005. “Effect of Enzymatic Hydrolysis on the Yield of Cloudy Carrot Juice and the Effects of Hydrocolloids on Colour and Cloud Stability during Ambient Storage.” *Journal of the Science of Food and Agriculture* 85 (3): 505–512.

Rabetafika, Holy Nadia, Vinciane Van Remoortel, Sabine Danthine, Michel Paquot, and Christophe Blecker. 2011. “Flaxseed Proteins: Food Uses and Health Benefits.” *International Journal of Food Science & Technology* 46 (2): 221–228.

Rana, Vikas, Parshuram Rai, Ashok K. Tiwary, Ram S. Singh, John F. Kennedy, and Charles J. Knill. 2011. “Modified Gums: Approaches and Applications in Drug Delivery.” *Carbohydrate Polymers* 83 (3): 1031–1047.

Reddy, Avanija, Don F. Norris, Stephanie S. Momeni, Belinda Waldo, and John D. Ruby. 2016. "The pH of Beverages in the United States." *The Journal of the American Dental* Association 147 (4): 255–263.

Rowland, G. G., Y. A. Hormis, and K. Y. Rashid. 2002. "CDC Bethune Flax." *Canadian Journal of Plant Science* 82 (1): 101–2.

Saha, Dipjyoti, and Suvendu Bhattacharya. 2010. "Hydrocolloids as Thickening and Gelling Agents in Food: A Critical Review." *Journal of Food Science and Technology* 47 (6): 587–597.

Sammour, Reda Helmy. 1999. "Proteins of Linseed (Linum Usitatissimum L.), Extraction and Characterization by Electrophoresis." *Botanical Bulletin of Academia Sinica* 40: 121-126.

"Saskatchewan Flax Development Commission - Varieties." n.d. Accessed June 5, 2017. https://saskflax.com/growing/varieties.php.

"Sensory Research of Food - Nutrition and Dietetics." n.d. Accessed May 6, 2019. https://nutrition.acadiau.ca/sensory-research-of-food.html.

Seow, W. K., and K. M. Thong. 2005. "Erosive Effects of Common Beverages on Extracted Premolar Teeth." *Australian Dental Journal* 50 (3): 173–178.

Shakeel, Azam, Hafiz Khuram Wasim Aslam, Muhammad Shoaib, Hafiz Arbab Sikandar, and Rabia Ramzan. 2013. "Effect of Various Hydrocolloids on Cloud Stability and Nutrition of Carrot Juice." J. Glob. *Innov. Agric. Soc. Sci* 1 (22–27).

Shannon, William M. 1984. "Mechanisms of Action and Pharmacology: Chemical Agents." In *Antiviral Agents and Viral Diseases of Man,* 55–121. Raven Press New York.

Shellis, R. Peter, John DB Featherstone, and Adrian Lussi. 2014. "Understanding the Chemistry of Dental Erosion." In *Erosive Tooth Wear,* 25:163–179. Karger Publishers.

Simas-Tosin, F. F., R. R. Barraza, C. L. O. Petkowicz, J. L. M. Silveira, G. L. Sassaki, E. M. R. Santos, P. A. J. Gorin, and M. Iacomini. 2010. "Rheological and Structural Characteristics of Peach Tree Gum Exudate." *Food Hydrocolloids* 24 (5): 486–93.

Singh, K. K., D. Mridula, Jagbir Rehal, and P. Barnwal. 2011. "Flaxseed: A Potential Source of Food, Feed and Fiber." *Critical Reviews in Food Science and Nutrition* 51 (3): 210–22.

Singh-Ackbarali, Dimple, and Rohanie Maharaj. 2014. "Sensory Evaluation as a Tool in Determining Acceptability of Innovative Products Developed by Undergraduate Students in

Food Science and Technology at the University of Trinidad and Tobago." *Journal of Curriculum and Teaching* 3 (1): 10–27.

Stewart, S., and G. Mazza. 2000. "Effect of Flaxseed Gum on Quality and Stability of a Model Salad Dressing." *Journal of Food Quality* 23 (4): 373–390.

Stone, Herbert, and Joel L. Sidel. 1998. "Quantitative Descriptive Analysis: Developments, Applications and the Future." *Food Technology (USA)* 52 (8): 48-52.

Szczesniak, Alina Surmacka, and Elizabeth Farkas. 1962. "Objective Characterization of the Mouthfeel of Gum Solutions." *Journal of Food Science* 27 (4): 381–85.

Tarpila, Anneli, Tero Wennberg, Simo Tarpila, and others. 2005. "Flaxseed as a Functional Food." *Current Topics in Nutraceutical Research* 3 (3): 167.

Tomoda, G., and Y. Asami. 1950. "Mucilage from Linseed or Linseed Meal." Japan Patent 3359.

Vaisey-Genser, Marion, and Diane H. Morris. 1997. "Flaxseed: Health, Nutrition and Functionality." Winnipeg, MB.: Flax Council of Canada.

Vardhanabhuti, B., and S. Ikeda. 2006. "Isolation and Characterization of Hydrocolloids from Monoi (Cissampelos Pareira) Leaves." *Food Hydrocolloids* 20 (6): 885–891.

Waldt, L. M. 1961. "Technology of Natural Gums and Stabilizers." Food Process 22 (4): 122.

Wang, Yong, Dong Li, Li-Jun Wang, and Benu Adhikari. 2011. "The Effect of Addition of Flaxseed Gum on the Emulsion Properties of Soybean Protein Isolate (SPI)." *Journal of Food Engineering* 104 (1): 56–62.

Wang, Yong, Dong Li, Li-Jun Wang, Shu-Jun Li, and Benu Adhikari. 2010. "Effects of Drying Methods on the Functional Properties of Flaxseed Gum Powders." *Carbohydrate Polymers* 81 (1): 128–133.

Wang, Yong, Martin J. T. Reaney, Xiaofeng Li, Wenzhen Liao, Shan Liang, Yinglai Teng, Youn Young Shim, and Peta-Gaye Gillian Burnett. 2017. Preparation Method And Use Of Linseed Polysaccharide Having Antiviral And Immunological Activity. WO/2017/005134, filed June 30, 2016, and issued January 12, 2017.

Wang, Yong, Li-Jun Wang, Dong Li, Necati Özkan, Xiao Dong Chen, and Zhi-Huai Mao. 2008. "Effect of Flaxseed Gum Addition on Rheological Properties of Native Maize Starch." *Journal of Food Engineering* 89 (1): 87–92.

Wang, Yong, Li-Jun Wang, Dong Li, Jun Xue, and Zhi-Huai Mao. 2009. “Effects of Drying Methods on Rheological Properties of Flaxseed Gum.” *Carbohydrate Polymers* 78 (2): 213–219.

Wannerberger, K., T. Nylander, and M. Nyman. 1991. “Rheological and Chemical Properties of Mucilage in Different Varieties from Linseed (Linum Usitatissimum).” *Acta Agriculturae Scandinavica* 41 (3): 311–319.

Warr, J., P. Michaud, L. Picton, G. Muller, B. Courtois, R. Ralainirina, and J. Courtois. 2003. “Large-Scale Purification of Water-Soluble Polysaccharides from Flaxseed Mucilage, and Isolation of a New Anionic Polymer.” *Chromatographia* 58 (5–6): 331–335.

Witvrouw, M, and E De Clercq. 1997. “Sulfated Polysaccharides Extracted from Sea Algae as Potential Antiviral Drugs.” General Pharmacology: *The Vascular System* 29 (4): 497–511.

Wu, Min, Dong Li, Li-jun Wang, Yu-guang Zhou, and Zhi-huai Mao. 2010. “Rheological Property of Extruded and Enzyme Treated Flaxseed Mucilage.” *Carbohydrate Polymers* 80 (2): 460–466.

Xu, Hui, and Lanping Sun. 2008. “Research Progress and Appliance in Food Industry of Flaxseed Gum” *China Condiment* 2008 (3).

Yanes, M, L Durán, and E Costell. 2002. “Effect of Hydrocolloid Type and Concentration on Flow Behaviour and Sensory Properties of Milk Beverages Model Systems.” *Food Hydrocolloids* 16 (6): 605–11.

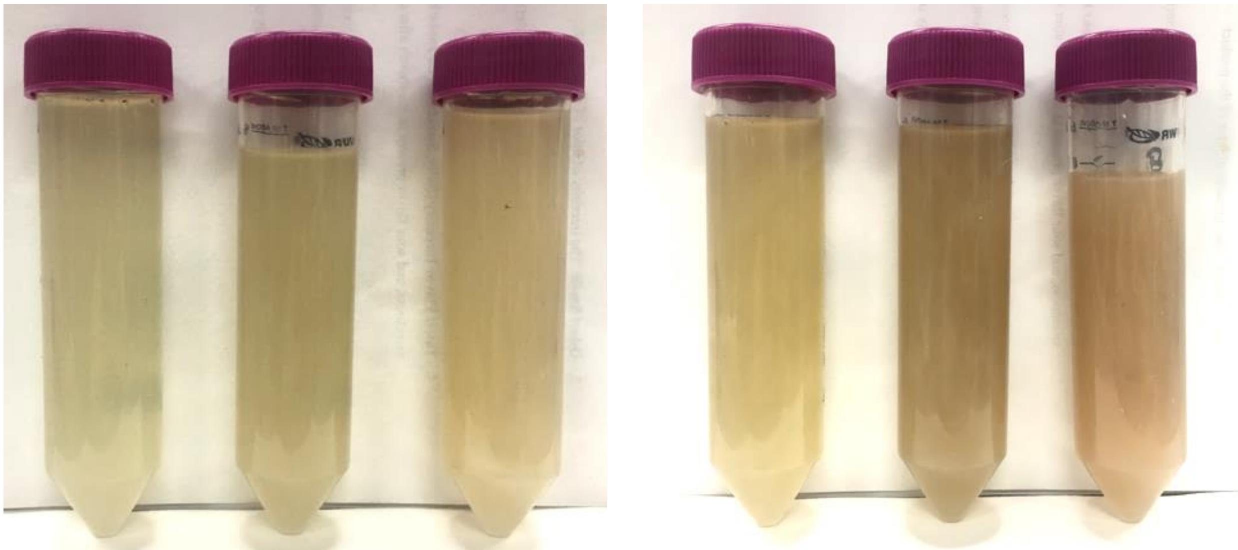
Zheng, Yun-ling, Dennis P. Wiesenborn, Kristi Tostenson, and Nancy Kangas. 2003. “Screw Pressing of Whole and Dehulled Flaxseed for Organic Oil.” *Journal of the American Oil Chemists’ Society* 80 (10): 1039–1045.

Zienkiewicz, Marc. 2017. “Breathing Life into Flax.” Germination. Accessed April 17, 2017. https://germination.ca/breathing-life-flax/.

Ziolkovska, Anna. 2012. “Laws of Flaxseed Mucilage Extraction.” *Food Hydrocolloids* 26 (1): 197–204.

Zuk, Magdalena, Dorota Richter, Jan Matuła, and Jan Szopa. 2015. “Linseed, the Multipurpose Plant.” Industrial Crops and Products, Advances in Industrial Crops and Products Worldwide: AAIC 2014 international conference, 75 (11): 165–77.

APPENDIX A: FLAXSEED GUM (FG) SOLUTION



(a) **(b)**

Figure A1 Flaxseed Gum (FG) extracted from whole flaxseed at 60°C (a) and 80°C (b) from 3 cultivars (from left to right on each figure: CDC Glas, CDC Bethune, CDC Sorrel).

APPENDIX B: PERMISSION TO REUSE FIGURES AND TABLES FROM EXISTING LITERATURE

This Agreement between Shuyu Shang ("You") and Elsevier ("Elsevier") consists of your license details and the terms and conditions provided by Elsevier and Copyright Clearance Center.

Your confirmation email will contain your order number for future reference.

printable details

License Number	4584920325567
License date	May 09, 2019
Licensed Content Publisher	Elsevier
Licensed Content Publication	Industrial Crops and Products
Licensed Content Title	Linseed, the multipurpose plant
Licensed Content Author	Magdalena Zuk,Dorota Richter,Jan Matuła,Jan Szopa
Licensed Content Date	Nov 30, 2015
Licensed Content Volume	75
Licensed Content Issue	n/a
Licensed Content Pages	13
Type of Use	reuse in a thesis/dissertation
Portion	figures/tables/illustrations
Number of figures/tables/illustrations	1
Format	both print and electronic
Are you the author of this Elsevier article?	No
Will you be translating?	No
Original figure numbers	Fig.1
Title of your thesis/dissertation	THE DEVELOPMENT OF AN ORAL REHYDRATION SOLUTION WITH FLAXSEED GUM
Expected completion date	Aug 2019
Estimated size (number of pages)	80

Figure B.1 Permission to reuse figure from Zuk et al. (2015).

License Number	4584320445772
License date	May 08, 2019
Licensed Content Publisher	Elsevier
Licensed Content Publication	Food Chemistry
Licensed Content Title	Characterisation of mucilages extracted from seven Italian cultivars of flax
Licensed Content Author	Thammarat Kaewmanee,Lucia Bagnasco,Soottawat Benjakul,Silvia Lanteri,Carlo F. Morelli,Giovanna Speranza,M. Elisabetta Cosulich
Licensed Content Date	Apr 1, 2014
Licensed Content Volume	148
Licensed Content Issue	n/a
Licensed Content Pages	10
Start Page	60
End Page	69
Type of Use	reuse in a thesis/dissertation
Portion	figures/tables/illustrations
Number of figures/tables/illustrations	4
Format	both print and electronic
Are you the author of this Elsevier article?	No
Will you be translating?	No
Original figure numbers	Fig. 4
Title of your thesis/dissertation	THE DEVELOPMENT OF AN ORAL REHYDRATION SOLUTION WITH FLAXSEED GUM
Expected completion date	Aug 2019
Estimated size (number of pages)	80

Figure B.2 Permission to reuse figure from Kaewmanee et al. (2014).

License Number	4616061346279
License date	Jun 25, 2019
Licensed Content Publisher	John Wiley and Sons
Licensed Content Publication	International Journal of Food Science & Technology
Licensed Content Title	Variation of composition and functional properties of gum from six Canadian flaxseed (Linum usitatissimum L.) cultivars
Licensed Content Author	Jun Liu, Youn Young Shim, Jianheng Shen, et al
Licensed Content Date	Sep 9, 2016
Licensed Content Volume	51
Licensed Content Issue	10
Licensed Content Pages	14
Type of use	Dissertation/Thesis
Requestor type	University/Academic
Format	Print and electronic
Portion	Figure/table
Number of figures/tables	1
Original Wiley figure/table number(s)	Table 1
Will you be translating?	No
Title of your thesis / dissertation	THE DEVELOPMENT OF AN ORAL REHYDRATION SOLUTION WITH FLAXSEED GUM
Expected completion date	Aug 2019
Expected size (number of pages)	80

Figure B.3 Permission to reuse figure from Liu et al. (2016).

License Number	4616080348325
License date	Jun 25, 2019
Licensed Content Publisher	Elsevier
Licensed Content Publication	Food Hydrocolloids
Licensed Content Title	Influence of genotype on chemical composition and rheological properties of flaxseed gums
Licensed Content Author	W. Cui,E. Kenaschuk,G. Mazza
Licensed Content Date	Apr 1, 1996
Licensed Content Volume	10
Licensed Content Issue	2
Licensed Content Pages	7
Type of Use	reuse in a thesis/dissertation
Portion	figures/tables/illustrations
Number of figures/tables/illustrations	1
Format	both print and electronic
Are you the author of this Elsevier article?	No
Will you be translating?	No
Original figure numbers	Table 1
Title of your thesis/dissertation	THE DEVELOPMENT OF AN ORAL REHYDRATION SOLUTION WITH FLAXSEED GUM
Expected completion date	Aug 2019
Estimated size (number of pages)	80

Figure B.4 Permission to reuse figure from Cui et al. (1996).